MOTOR OVERFLOW IN CHILDREN AND DOWN SYNDROME ADULTS

MOTOR OVERFLOW IN NONRETARDED CHILDREN AND DOWN SYNDROME ADULTS

By

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ABSTRACT

Two experiments are reported that examine motor overflow in Down syndrome and nonretarded persons. The two main purposes of the experiments were to determine the utility of motor overflow as a diagnostic tool and the relationship between motor overflow and transfer of training. In Experiment 1, nonretarded children and adults performed a unimanual finger-sequencing task. It was found that motor overflow follows a developmental course. As well, a positive relationship was found between motor overflow and intermanual transfer of training, and children were able to reduce their ipsilateral motor overflow with training. These results indicate that caution should be taken in diagnosing central nervous system dysfunction of a structural nature using motor overflow. In Experiment 2, similar procedures were used to examine younger children and Down syndrome adults. It was found that with conscious effort, even the children could reduce their motor overflow. A positive relationship between transfer of training and motor overflow was also evidenced in Down syndrome subjects. As well, there was greater transfer of training from the left hand to the right hand than the reverse, in both Down syndrome adults and young, nonretarded children. These findings are discussed in reference to factors affecting the appearance of motor overflow and what can be learned about cerebral specialization in nonretarded and special populations.

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INTRODUCTION

Two experiments were designed to examine manual asymmetries in inter-limb transfer of training and motor overflow and their relationship to cerebral asymmetries and left-hemipshere organization for the control of movement. A secondary purpose was to examine asymmetries in Down syndrome persons to gain further insight into the manner in which these individuals control limb movements. Before describing these experiments it is necessary to review research on cerebral specialization and motor asymmetries both in non-Down syndrome and Down syndrome persons.

Cerebral Specialization

Although the study of brain function and laterality has been popularized in recent years, the notion that the two cerebral hemispheres have different functions has had a long history (see Milner, 1971 for review). Throughout this history, there has been an emphasis placed on research examining speech and language asymmetries in both the injured and intact brain. Classic studies by Sperry and associates supported left-hemisphere dominance of expressive language function (Gazzaniga, 1967; Gazzaniga, Bogen & Sperry, 1965; Gazzaniga & Sperry, 1967). Commissurotomized patients were unable to write or verbally describe visual material presented to their left visual field or objects manipulated by their left hand. The left hand and left visual field are contralaterally controlled by the right hemisphere. However, when nonverbal answers were required subjects were able to correctly match pictures of objects flashed to their right hemisphere with objects held in their left hand. Therefore the studies supported the notion of left-hemisphere superiority for expressive language and only rudimentary understanding of verbal input by the right hemisphere.

Dichotic Listening Asymmetries

Kimura (1967) examined cerebral specialization of language function in the intact brain with dichotic-listening studies. The simultaneous presentation of auditory language stimuli to both ears revealed a right-ear superiority in recall accuracy. The right-ear advantage for verbal material was explained by its direct access to the left-hemisphere's auditory cortex through crossed pathways that occlude weaker ipsilateral pathways. A left-ear disadvantage was expected since according to Kimura, verbal material would be carried to the right hemisphere by the dominant crossed pathways and would be passed indirectly across the corpus callosum to left-hemisphere speech centres. Left-ear information would either degrade or take longer to reach the speech centre through callosal transmission.

If one accepts Kimura's notion of right-ear advantage for verbal material reflecting direct access to left-hemisphere speech centres then a left-ear superiority in dichotic-listening may indicate specialized functions of the right hemisphere. Kimura (1964) noted that upon dichotic presentation of music, a left-ear superiority was obtained indicating right-hemisphere dominance for the analysis of music. Thus, the nature of auditory material presented affects the direction of ear advantage and provides insight into the complex aspect of cerebral specialization.

Although Kimura's model and the dichotic-listening paradigm have advanced the study of cerebral specialization, strong conclusions concerning the organization of the brain are difficult due to problems inherent in the dichotic paradigm. In his review, Bryden (1982) noted that magnitude and direction of ear effects can be influenced by many things including the type of stimulus presented, the speed of presentation and recall instructions. As well, order biases, attentional biases, perceptual differences, and memory trace differences have also been offered as explanations for ear advantages (see Bryden, 1982 for review). All of these factors must be considered in the interpretation of dichotic-listening data.

Motor Asymmetries

In addition to studies examining asymmetries in visual and auditory perception, asymmetries in motor performance recently have provided insight into some aspects of cerebral specialization. Much of the research attempting to link cerebral specialization and asymmetric motor performance was conducted on clinical populations. Wyke (1967, 1971b) found that patients with right-hemisphere damage suffered only left-hand performance deficits on a sequential motor task whereas left-hemisphere damaged patients exhibited a bilateral decrement. Wyke (1967, 1971a, 1971b) demonstrated that the effects of right- and left-hemisphere damage on motor performance were not symmetrical despite the contralateral representation for distal musculature in the two hemispheres (Brinkman & Kuypers, 1972).

Kimura and associates extended the research on motor asymmetries in movement control. Kimura and Archibald (1974) tested right- and left-hemisphere damaged patients on manual sequencing tasks. Subjects were required to copy isolated hand postures and then perform relatively unfamiliar hand movements. Copying the single postures was not difficult for either brain-damaged group however differences became evident when the task required subjects to organize a sequence of movements. The left-hemisphere damaged group became significantly impaired compared to the right-hemisphere damaged group when copying these movement sequences. The deficit in the left-hemisphere damaged subjects was also bilateral in nature. Unfortunately, comparisons between the hands were not possible in the right-hemisphere damaged group since the majority of this group were hemiplegics. Had paresis not been involved in the right-hemisphere damaged group, perhaps a deficit in only the left hand would have been evidenced for movement sequencing (cf. Wyke 1967, 1971b). Kimura suggested that the bilateral deficit exhibited by the left-hemisphere damaged group was due to the disruption of that hemisphere's control for the production of a series of complex movements.

In more recent work, Kimura (1977) has shown that a left-hemisphere damaged group, of aphasics performed sequential movement more poorly than nonaphasics. This suggested to Kimura that the movements of oral musculature as well as brachial musculature are controlled by a left-hemisphere movement generator. Mateer and Kimura (1977), supported this conclusion in a study that employed left-hemisphere damaged adults with nonfluent aphasia (motor impairment of oral musculature) and fluent aphasia (impairment of phoneme production). During the production of simple nonverbal movements one would certainly expect impairment in the nonfluent aphasics but not in the fluent aphasics. The authors examined the performance of aphasics on simple and complex oral motor tasks, both verbal and nonverbal. As expected, the results indicated great difficulty in simple and complex nonverbal tasks for the nonfluent aphasics however, fluent aphasics were impaired only on the complex nonverbal tasks. Thus fluent aphasics, although able to perform several single oral movements, failed to string the same oral movements into a series. Thus, the authors regard fluent aphasia as an impairment in putting movements together in a specified sequence which again suggests left-hemisphere specialization for motor function.

The study of cerebral specialization has been advanced by the examination of manual asymmetries in the intact brain. Todor and Kyprie (1980) examined rapid tapping performance in a group of right-handers and found a faster and less variable rate of finger tapping in the dominant hand compared to the non-dominant hand. Consistent with other researchers (Peters, 1976; Taylor & Heilman, 1980; Todor, Kyprie & Price, 1982; Todor & Smiley, 1985), the authors contended that the hand differences were due to the differential ability of the two hemispheres to process certain types of information. The superior tapping performance with the right hand reflected the left-hemisphere control of sequential movement. The authors also associated the increased left-hand tapping variability with the relative difficulty the right hemisphere has in modulating force (Todor & Smiley, 1985).

Researchers have also suggested that manual asymmetries in both tapping and visual aiming tasks stem from hemispheric differences in force modulation (Peters, 1980; Roy & Elliott, 1986; Todor & Smiley, 1985). Experiments have evidenced right-hand performance advantages due to superior control of force by the left-hemisphere (see Todor & Smiley, 1985 for review).

To further investigate left-hemisphere motor dominance, Taylor and Heilman (1980) examined sequential finger movements in adults utilizing a transfer of training paradigm. Subjects performed one pre-training trial with each hand on a complex, finger-sequencing task. Following this measure of pre-training performance, half of the subjects performed 25 trials with their right hand and half of the subjects performed 25 trials with their left hand. Finally, all subjects performed one additional post-training trial with each hand and the transfer between hands was assessed. The study demonstrated that left-hand training resulted in greater transfer of training to the right hand than vice versa. The authors suggested that this asymmetric transfer of training in the left- to- right direction was due to the left-hemisphere's dominance for movement control. Taylor and Heilman maintain that the right hand was able to directly access skills learned by the left hand which were stored in the left hemisphere, however the left hand had only only indirect access to skills learned by the right hand through the corpus callosum. Therefore it appears that the utilization of the transfer of training paradigm with intact subjects has also been valuable in examining left-hemisphere control of sequential movement.

Cerebral Specialization in Down Syndrome Persons

Perceptual Asymmetries

The role of cerebral specialization in language and sequential movement production also has been examined in Down syndrome individuals in an attempt to gain insight into their language difficulties. Dichotic-listening studies have indicated that unlike nonretarded persons, Down syndrome individuals have a right-hemisphere dominance for speech perception (Hartley, 1981; Pipe, 1983; Zekulin-Hartley, 1981). Zekulin-Hartley (1981) examined ear advantages on a dichotic-listening task in nonretarded children, Down syndrome children, and non-Down syndrome children. Results evidenced a right-ear superiority for the nonretarded children and non-Down syndrome children but an atypical left-ear superiority in Down syndrome children. Thus the right-hemisphere superiority for speech perception seems to be related to the syndrome itself, not simply retardation. Efforts to replicate the asymmetry with more complex linguistic stimuli (Hartley, 1981) and with auditory training using high frequency words (Pipe, 1983) also revealed the atypical right hemisphere representation for speech perception in Down syndrome persons.

Hartley (1982) investigated language processing difficulties in Down syndrome, non-Down syndrome and nonretarded children using The Token Task for Children (DiSimoni, 1978). On sections of the test requiring sequential processing of complex syntactic structures, the Down syndrome group performed the poorest of the three groups whereas on spatial tasks, the two groups of retarded children were equivalent. Hartley suggests that the peculiar left-ear dominance on linguistic tasks (Hartley, 1981; Pipe, 1983; Zekulin-Hartley, 1981) is linked to their sequential-language deficits. If there is a biological basis for the sequential-language problems in Down syndrome persons then perhaps an atypical pattern of cerebral specialization can explain sequential processing deficits documented by other researchers as well (Ashman,1982).

Although several dichotic-listening studies suggest reversed lateralization for language in Down syndrome persons (Hartley, 1981; Pipe, 1983), this work has been criticized. Tannock, Kershner and Oliver (1984), contest that methodological errors account for perceptual asymmetries in previous studies. Tannock et al. (1984) suggested that the test stimuli and required subject responses employed in previous research primed the right hemisphere, creating the typical left ear-advantage in Down syndrome subjects for linguistic material. Using a selective listening procedure, Tannock et al. (1984) failed to find any ear asymmetries in their Down syndrome subjects.

In addition, Elliott, Edwards, Weeks, Lindley, and Carnahan (1987), contend that a model of reversed cerebral specialization may be too simplistic. Most studies examining Down syndrome persons' atypical lateralization for language studied ear-differences in speech perception, while Elliott et al. (1987) researched cerebral asymmetries in individuals with Down syndrome by examining speech production. Using a dual-task procedure, Elliott et al. (1987) found that sound-shadowing high frequency words disrupted rapid finger-tapping with the right-hand in male Down syndrome persons and nonretarded male control subjects. This finding implies left-hemisphere control of speech production in both Down syndrome and nonretarded persons. Thus, there appears to be a dissociation between cerebral areas responsible for speech perception (right hemisphere) and speech production (left hemisphere). This dissociation may account for language difficulties in Down syndrome persons since they are both integral components of normal language function.

Motor Asymmetries in Down Syndrome Persons

To examine motor asymmetries in Down syndrome persons Elliott, Weeks and Jones (1986) examined hand differences in tapping variability on a single-finger tapping task since several investigators have suggested that variability of movement timing is an indicator of the mode of movement control (Todor & Kyprie, 1980; Todor et al., 1982). Down syndrome subjects evidenced the same pattern of variability as nonretarded control subjects; that is, greater finger-tapping variability with left-hand performance. This is particularly interesting since hand differences in variability may reflect differential processing preferences of the two hemispheres (Todor et al., 1982). Thus, it seems that like the nonretarded, Down syndrome persons also have a right-hemisphere superiority for non-sequential or preprogrammed movement. Thus again, some of the sequential language problems suffered by Down syndrome persons may stem from the fact that the sequential processor essential in speech perception is dissociated from their speech perception centre.

In order to further investigate sequential-language processing deficits in Down syndrome persons, Elliott (1985) examined manual asymmetries on a sequential movement task. Using a transfer of training paradigm similar to Taylor and Heilman (1980), Elliott had Down syndrome adults and nonretarded controls matched on chronological age (CA) learn a rapid, finger-tapping task with either the right or left hand. The results yielded an asymmetric transfer of training pattern in Down syndrome individuals similar to nonretarded adults, indicating that in both groups the left cerebral hemisphere is specialized for movement sequencing. Elliott's rationale for the left- to- right direction in asymmmetric transfer of training was the differential involvement of the hemispheres in task performance. Elliott suggested that during left-hand performance both hemispheres are involved (sequential processor in the left hemisphere, and contralateral motor control in the right hemisphere) while only the left hemisphere is involved in right hand performance. As well, Elliott posited that since receptive language seems to be a right hemisphere function in Down syndrome persons (Hartley, 1981; Pipe, 1983), and complex movement sequencing, including speech production, is a left hemisphere function, then perhaps Down syndrome individuals are processing language with the neural mechanisms not equipped for the task (see Elliott, Weeks & Elliott, in press, for review).

Motor Overflow - General

Motor overflow is a phenomenon that has been described as involuntary activity accompanying intended movements, commonly found in the passive limb contralateral to the extremity performing the voluntary act (Cohen, Taft, Mahadeviah & Birch, 1967). Motor overflow is commonly seen in young children, but gradually diminishes with age (Abercrombie, Lindon & Tyson, 1964; Cohen et al., 1967, Connolly & Stratton, 1968). Motor overflow is now being used in clinical settings as a diagnostic tool for CNS dysfunction since it follows a developmental course during normal maturation but is also found in excessive amounts in individuals with gross neurological disorders such as paresis (Hopf, Schlegel & Lowitzsch, 1974; Woods & Teuber, 1978). More motor overflow also has been observed in children with learning disabilities, hyperkinesis and mental retardation compared to age-related controls (Abercrombie et al.,1964; Cohen et al., 1967; Denckla & Rudel, 1978; Fog & Fog, 1963; Szatmari & Taylor, 1984; Touwen & Prechtl, 1970). While the notion that excess motor overflow reflects CNS dysfunction is supported by research on clinical populations, there remain several difficulties in its utility as an index of maturational status.

Although the utility of motor overflow as a tool for assessing developmental status and neurological impairment may seem obvious due to its manifestation in people with either major or more subtle neurological problems, there may be several different reasons other than neurological abnormality for its appearance. Learning disabled children, for example, exhibit excessive amounts of motor overflow, however, these children also have been found to adopt inefficient strategies to complete tasks, partly due to their outerdirectedness (Turnure & Zigler, 1964). The use of motor overflow in a diagnostic practice involves a small number of clinical trials on unusual tasks such as finger spreading and inverted or everted foot walking. However, as in the example of learning disabled children, perhaps they exhibit more overflow because they have simply not adopted the most efficient strategy to accomplish the task. If this is a possiblity, then care should be taken in the use of motor overflow in the diagnosis of CNS dysfunction.

The appearance of motor overflow has also been influenced by the amount of force used in the performing hand. For example, the stronger the volitional force an individual must generate relative to his maximum, the more pronounced the co-contractions appear (Cernacek, 1961; Fog & Fog, 1963; Stern, Gold, Hoin & Barocas, 1976; Todor & Lazarus, 1985). Several studies have not controlled for this relative force variable and have had all subjects performing at a proportion of some absolute force (Abercrombie et al., 1964; Connolly & Stratton, 1968; Fog & Fog, 1963). This presents a confound in the examination of developmental trends and gender differences. Recently, Todor and Lazarus (1986) in an effort to better quantify motor overflow, employed a clip-pinching task to directly assess the relationship between exertion levels and the intensity of involuntary co-contractions in children. Subjects were required to squeeze a clip at fixed percentage of their own maximal force with one hand while any squeezing taking place in the passive hand was measured as motor overflow. Results indicated that co-contraction force increased as the percentage of maximal force increased. This finding suggested that overflow in young children has been over-estimated and overflow in older children has been under-estimated. Thus the developmental trend evidenced in past research may be misleading since the relative exertion levels, which were often not controlled, have been shown to influence the amount of overflow displayed. Similarly, women display more overflow than men because of the greater proportional effort needed by women to accomplish the same task (Connolly & Stratton, 1968). Furthermore, the relative exertion level must be controlled when examining motor overflow asymmetries in hemiparetic subjects. The weaker, paretic hand must perform at a higher percentage of its maximum force than the stronger, non-paretic hand, perhaps resulting in excessive motor overflow from the paretic hand.

Asymmetries in Motor Overflow

In addition to detecting the positive relationship between exertion level and the manifestation of motor overflow, Todor and Lazarus (1986) observed a lateral asymmetry of motor overflow among their subjects. More overflow was exhibited in the right hand when the left hand was active than the converse. This asymmetry was shown to exist even when the relative strength of the two hands was taken into consideration. Consequently, any asymmetry in overflow could not have been due to the weaker left hand performing at more of its maximum than the right hand as had previously been proposed.

In attempting to explain the asymmetry of overflow, Todor and Lazarus (1985) drew upon several models of cerebral specialization. Research by Semmes (1968) on brain-lesioned patients presented evidence to suggest that the two hemispheres have different representations for sensorimotor functions. Semmes contended that functions are focally represented in the left hemisphere and diffusely represented in the right hemisphere. Todor and Lazarus have expanded the idea by suggesting that when the right hand is active, neural activity is localized in the left hemisphere, however when the left hand performs, neural activity is diffusely represented in the controlling right hemisphere and thus activity overflows into cerebral areas responsible for right-hand control.

Another model which has been used to explain the lateral asymmetry in manual performance and motor overflow was proposed by Kimura and Archibald (1974). As discussed earlier, these authors contend that the left hemisphere is specialized not only for verbal functions but for the motor control of both hands, especially for motor skills demanding complex, sequential movements. This proposal is based on evidence indicating greater impairment on sequential motor tasks after left-hemisphere damage as compared to right-hemisphere damage. Todor and Lazarus use this model to explain asymmetries in motor overflow. They suggested that when the left hand is active, both hemispheres are involved in movement control thereby increasing the spread of neural activity to the other (right) hand. Conversely, since only the left hemisphere is involved in right hand control, overflow to the left hand is minimal. This explanation is similar to proposals regarding asymmetric inter-limb transfer of training.

In their final model, Todor and Lazarus suggest that since the right hand is more practiced and efficient, neuronal activity patterns would be more refined. The left hand, being less efficient, would be controlled by a "more diffuse network of cortical neurons" (p. 35), giving rise to a greater possibility for the spread of neural activity to the right hand.

The present research was designed to further explore the relationship between motor overflow and transfer of training asymmetries and to provide insight into the lateralization of movement control functions in both Down syndrome individuals and nonretarded persons. As well, both experiments address the effect of training on the appearance of motor overflow in nonretarded and special populations. The first of two experiments examined motor overflow and the transfer of training on a finger-sequencing task in adults and children. One purpose of Experiment 1 was to determine whether the degree of asymmetry in transfer of training and motor overflow follows a developmental course and whether the two phenomena are related. Another purpose was to determine the influence of training on motor overflow.

It would appear that theories posited by researchers on asymmetries in transfer of training and asymmetries in motor overflow have a common underlying base. Recall that Elliott (1985), following the logic of Taylor and Heilman (1980), suggested that the finding of greater transfer of training from the left hand to the right hand than the reverse in both Down syndrome and nonretarded subjects, was indicative of left-hemisphere specialization for sequential movement control. Also recall that Todor and Lazarus (1985), following the logic of Kimura and Archibald (1974), explained that the asymmetry in motor overflow (also in a left to right direction), was the result of both hemispheres being involved in the motor control of the left hand while only the left hemisphere was involved in right hand control. If these two phenomena have a common basis, then perhaps both can be used to study cerebral specialization and its influence on movement control in general.

Determining the relationship between motor overflow and transfer of training in Experiment 1 was a preliminary step to aid in the investigation of motor overflow asymmetries in the mentally retarded. Experiment 2 was designed to compare motor overflow in

Down syndrome adults and nonretarded children to further understand cerebral asymmetry in Down syndrome persons. Patterns of cerebral dominance in populations with an atypical genetic makeup are of interest since they can potentially provide insight into the genetic basis of cerebral specialization in nonretarded individuals. As well, a better understanding of Down syndrome persons' cerebral organization, gained through the examination of motor overflow asymmetries, has implications for understanding language aquisition difficulties and movement control problems in this population.

It was of interest in Experiment 2 to determine the quantity of motor overflow exhibited in both groups, as well as the asymmetry in motor overflow. Recall that Elliott (1985) evidenced asymmetric transfer of training in a left to right direction in Down syndrome persons. If asymmetric motor overflow in Down syndrome persons occurs in a similar direction as the transfer of training, and the two phenomena are related based on the findings of Experiment 1, then perhaps asymmetries in motor overflow can confirm left hemisphere dominance in the control of complex movements in Down syndrome persons. Also examined were the effects of training on motor overflow and the effectiveness of efforts to consciously inhibit motor overflow.

Experiment 1

Experiment 1 examined motor asymmetries and motor overflow in young children and adults. The experiment was designed so that both performance of the active hand during rapid, finger-tapping could be observed and motor overflow in the passive hand could be measured. There were four purposes to Experiment 1: 1) to confirm the developmental course of motor overflow, 2) to determine whether practice affects the appearance of motor overflow, 3) to confirm the existence of asymmmetries in both motor overflow and transfer of training in children and adults, and 4) to determine whether a relationship exists between motor overflow and transfer of training. Purposes 1 and 2 have relevance to understanding the nature of motor overflow and its utility as a diagnostic tool in neurodevelopmental delay. Purposes 3 and 4 have relevance to understanding the basis of movement control asymmetries.

Young children and adults performed a rapid, unimanual finger-lifting task. One hand was active while the other hand remained passive in order to observe unintended movement (motor overflow). All subjects performed several pre-training trials with each hand. Half of the subjects were then trained on their right hand and half of the subjects were left-hand trained. Finally, several post-training trials were performed with each hand.

In relation to the first purpose, one would predict children to exhibit more motor overflow than adults since research indicates motor overflow decreases with CNS maturation (Abercrombie et al., 1964; Cohen et al., 1967; Connolly & Stratton, 1968). It was of interest to examine the effect of training on motor overflow. If motor overflow can be used as an index of maturational status, then the amount of practice received on the task should have little effect on the amount of motor overflow exhibited. However, if training decreases motor overflow, the utility of motor overflow as a clinical index of neurodevelopmental delay needs to be examined further.

In regard to Purposes 3 and 4, it was of interest to examine asymmetric transfer of training in the present study since both Elliott (1985) and Taylor and Heilman (1980) employed adults to obtain the asymmetry.

If an asymmetry in the young children is found then it would indicate lateralization for movement control at an early age.

Research indicated that in right-handed males, there is less right-hand variability reflecting the left-hemisphere's sequential processing ability (Todor, Kyprie & Price, 1980; Elliott et al., 1986). If one is to accept Kimura and Archibald's (1974) theory involving the left-hemisphere's dominance in the control of complex, sequential movement, one could predict greater transfer of training and motor overflow from left hand performance to the right hand than vice versa. Theories of manual asymmetries seem to have a common basis related to differential processing abilities of the two hemispheres. Based on the similarity in explanations for asymmetric transfer of training and motor overflow a positive relationship between the two phenomena was predicted.

METHOD

Subjects

Subjects were 24 right-handed male children (M age = 9 yrs, 7 mos, SD = 10 mos) and 24 right-handed adult males (M age = 20 yrs, 4 mo, SD = 2 yrs, 1 mo). The children were volunteers from a sports camp at McMaster

University and adults were university students participating in the study for course credit. The subjects had no known developmental deficits.

Apparatus

The apparatus consisted of eight telegraph keys mounted to a wooden board. The keys were aligned so that the four fingers of each hand could be comfortably placed and spread to rest on each key. The telegraph keys were connected to counters sensitive to lifts releasing a minimum of 45 grams of weight from the depressed keys.[1] A stopwatch was used to assess performance times.

Procedure and Design

Prior to the experiment, the subjects' dominance was determined. The subjects were asked to print their names, use a hammer, throw a ball and manipulate a spoon since research has indicated these actions are the best predictors of dominance (Bryden, 1977). To be included in the study, subjects were required to be right-handed in writing and to have used the right hand in at least two of the other three actions.

Subjects were told to begin each trial with all eight keys depressed and then upon a verbal signal from the experimenter, lift then replace each finger on one hand in a predetermined sequence. Subjects were told to go as fast as possible without making any errors. The sequence of lifts was as follows: (1) third finger, (2) index finger, (3) fourth finger, and (4) second finger. The sequence of each lift was marked on the base of each key while being easily visible to the subject. The subjects were also instructed to lift only one finger at a time and to return it to the key before lifting the next finger in the sequence.

Subjects were required to perform five correct sequences on every trial. If a mistake occurred (a finger lifted out of sequence) subjects were told to begin the sequence over again. Subjects were told to stop upon completion of five correct sequences. Each trial was timed, and total number of lifts were recorded in the performing hand and the passive hand. Although lifts were not recorded for the index finger, the finger still performed in the sequence. Errors were also noted - the finger lifted out of sequence and the correct finger. Lifts accompanying the correct lift on the performing hand were not counted as errors. They were operationally defined as ipsilateral motor overflow. Only a finger lifted out of order was deemed an error.

Subjects were given one practice trial with each hand. Subjects then performed four pre-training trials with each hand, alternating hands on each trial. The order that subjects began the trials (right or left) was counterbalanced across subjects since research indicated that the order of hand use may influence asymmetric motor overflow (Todor & Lazarus, 1985).[2] No knowledge of results was given on pre-training trials. In the training phase, half of the subjects trained with their right and half with their left hand. Twelve training trials (three blocks of four trials) were performed. The experimenter gave the subject feedback concerning the time for each trial. Finally, subjects performed four post-training trials with each hand in the same manner as the pre-training trials. As for the pre-training trials, no feedback about performance was given.

The three dependent variables examined in the present study were active hand performance (time to complete five correct sequences), and ipsilateral and contralateral motor overflow (_M_ number of unintended lifts per hand).[3] Pre-training scores for both hands on performance time, contralateral and ipsilateral motor overflow were averaged across only the first two of the four trials since it was apparent that performance had dramatically improved by the third trial. Post-training scores were averaged across all four trials. Ipsilateral motor overflow was determined by using the error data. When a mistake occurred during a sequence, that sequence was not counted. Therefore, all lifts performed during the incorrect sequence were deducted from the total number of lifts for that trial. The basic design of the study was 2 (Training Group) x 2 (Age) x 2 (Time of Test) x (Hand) mixed design with repeated measures on the last two factors. Post hoc analyses (Tukey a, $p<.05$) were performed on all significant effects.

RESULTS

Performance (Pre-Post)

Active Hand

A four-factor analysis of variance for time to complete five correct sequences revealed a main effect for age, $F(1,44) = 48.75$, $p<.001$, $\omega^2 = .32$ and for time of test, $F(1,44) = 60.09$, $p<.001$, $\omega^2 = .12$. As expected, children did not perform as well as adults and overall there was a general improvement in performance from the pre-training to post-training trials. The analysis also revealed an age x time of test interaction, *F* (1,44) = 29.71, *p* = <.001, ω^2 = .06. As seen in Table 1, post hoc analysis evidenced improved performance in the children, however, adult performance did not improve with training. Perhaps this represents a ceiling effect in the adults (see Table 1).

A significant training group x hand interaction, *F* (1,44) = 5.10, *p* = .027, ω^2 = .003 and an age x training group x time of test interaction, *F* (1,44) = 4.01, *p* = .048, ω^2 = .006 were also revealed in the analysis of active hand performance. As evident in Table 1, the right-hand trained subjects performed better with their right hand, while for left-hand trained subjects there was no difference between the hands.

Post hoc analysis of the age x training group x time of test interaction revealed that both left-hand trained and right-hand trained children improved over time and the greatest improvement was found in the children that trained with their left hand. The adults evidenced no improvement with practice. Thus, evidence is provided for asymmetric transfer of training in children since there was greater improvement in <u>both</u> hands when children trained with their left hand.

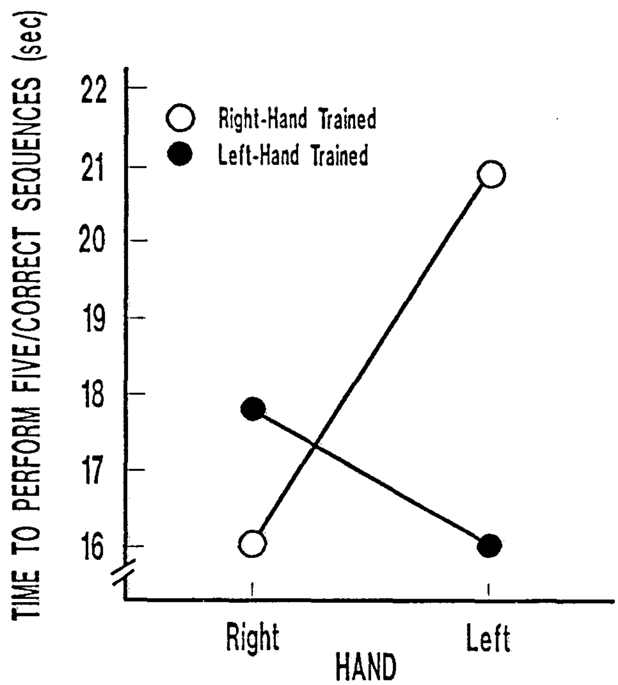
Table 1

Experiment 1 - Performance of Active Hand (sec) as a Function of Age, Training Group and Time

		LT			RT		
		RH	LH	Mean	RH	LH	Mean
Children	Pre	34.08	34.13	34.11	25.67	27.13	26.40
	Pos	18.98	17.33	18.16	14.96	19.90	17.43
Adults	Pre	12.83	12.86	12.86	12.67	14.25	13.46
	Pos	10.77	11.19	10.98	10.04	11.94	10.99
Mean		19.17	18.88		15.84	18.31	

Also evident in Table 1, is the troublesome fact that the differences between training groups in the three-way interaction lie not in post-training scores but in the pre-training scores. Thus while left-hand trained children improved to a greater extent than right-hand trained children, this improvement simply washed out initial pre-training differences related to random influences. To further examine the training group and hand effects in these data, it was decided to analyze post-training data alone, using overall pre-training scores as a covariate. In this way, training groups are statistically equated for pre-training performance. Thus, two separate 2 (Training Group) x 2 (Hand) analyses of covariance were performed on adult and children post-training scores with pre-training performance collapsed over hand as the covariate.

The analysis of covariance for the children's scores revealed a main effect for hand, $\underline{F}$ $(1,22) = 6.92$, $\underline{p} = .014, \omega^2 = .04$, and training group x hand interaction, $\underline{F}$ $(1,22) = 27.68$, $\underline{p} < .001, \omega^2 = 18$. As evident in Figure 1, the right hand performed better than the left hand. The interaction indicated that the children exhibited asymmetric transfer of training



<u>Figure 1.</u> Experiment 1 - Post-training Active Hand Performance in Children (sec) as a Function of Hand and Training Group

since with right-hand training there were large differences between the hands but with left-hand training both hands performed equally well. The analysis of covariance for the adult scores revealed a main effect for hand, F (1,22) = 7.78, p = .01, ω^2 = .091, evidencing better performance with the right hand than the left hand (M = 10.41 vs 11.56). Thus, when adult and children's performance scores were adjusted for pre-training differences in training groups, the asymmetric transfer of training pattern was still evident in the children's results.

Contralateral Overflow

A four-way analysis of variance on contralateral overflow scores yielded a main effect for age, F (1,44) = 22.30, p < .001, ω^2 = .15, a main effect for hand, F (1,44) = 7.22, p < .009, ω^2 = .02, and a hand x training group interaction, F (1,44) = 4.85, p = .03, ω^2 = .01. Consistent with the developmental literature on motor overflow (Todor & Lazarus, 1985), children exhibited more motor overflow than adults (see Table 2). Support for the lateral asymmetry in motor overflow found in previous studies (Todor & Lazarus, 1985) was also provided since greater overflow was exhibited by both adults and children with left-hand performance.

Table 2

Experiment 1 - Contralateral Motor Overflow (Mean Number of Lifts) as a Function of Age, Training Group, and Active Hand

	Children		Adults	
Group	RH	LH	RH	LH
RT	4.06	8.83	.98	3.68
LT	8.35	8.16	.52	1.46
Mean	6.21	8.50	.75	2.57

The training group x hand interaction indicates that there was less overflow from the right hand when subjects were right-hand trained, while both hands were equivalent with left-hand training. While this pattern might be predicted for post-training scores, it is unclear why pre-training means were affected in this manner.

Ipsilateral Overflow

A four-way analysis of variance yielded a main effect for age, F (1,44) = 10.25, p = .002, ω^2 = .10, and an age x time of test interaction, F (1,44) = 6.08, p = .02, ω^2 = .03. The results indicated that children exhibited more ipsilateral overflow than adults. Moreover, children are able to reduce their ipsilateral overflow with training whereas adults showed no reduction (M Number of Lifts: Children pre= 37.64, post = 31.68; Adults pre = 25.49, post = 28.01). Thus in children, the occurence of ipsilateral overflow may be influenced by task efficiency.

Correlational Analyses

Correlational analyses were conducted to investigate the relationship between transfer of training and contralateral motor overflow. A transfer of training score for each subject was calculated by determining the difference between post-training and pre-training performance of the untrained hand, with a positive score indicating positive transfer. Motor overflow scores were based on pre-training measures since these measures were assumed to be the least affected by our experimental manipulation. Initially, separate correlations were calculated for each of the four age-training groups. While for the adults and right-hand trained children, no relationship was found between overflow and transfer of training ($p > .10$), a significant positive correlation between overflow and transfer of training was evident for children trained with their left hand, r (10) = .603, $p < .05$. This positive correlation was also evident for children when the data were collapsed across training groups, r (22) = .503, $p < .05$. Thus, it would appear that the greatest transfer of training was evident in children who exhibited the most contralateral motor overflow.

Training Phase

Active Hand

A 2 (Training Group) X (Age) X 3 (Block) mixed analysis of variance with repeated measures on the last factor was employed to assess active hand performance during training trials. The analyses revealed a main effect for age, $F(1,44) = 42.40$, $p<.001$, $\omega^2 = .40$, a main effect for blocks, $F(2,88) = 4.81$, $p = .008$, $\omega^2 = .01$, and an age X block interaction, $F(2,88) = 4.82$, $p = .01$, $\omega^2 = .008$. As expected, the children were slower than the adults. Post hoc analysis of the main effect for blocks, evidenced an improvement by subjects over training trials with the third block being significantly better than the first block of trials. Consistent with the performance data, the age X block interaction revealed no improvement in the adults over blocks but the children were able to decrease their time.

Contralateral Motor Overflow

A three-way mixed ANOVA on contralateral motor overflow yielded a main effect for age, $F(1,44) = 8.43$, $p = .005$, $\omega^2 = .07$, and a main effect for group, $F(1,44) = 3.69$, $p = .058$, $\omega^2 = .026$. As in the pre - and post - training phases , children showed more contralateral motor overflow than adults. The group effect was the result of the left-trained subjects exhibiting more contralateral motor overflow than the right-trained subjects.

Ipsilateral Motor Overflow

The three-way mixed ANOVA for ipsilateral motor overflow resulted in a main effect for age, $F(1,44) = 4.60$, $p = .035$, $\omega^2 = .054$, with the children, once again, exhibiting the most ipsilateral motor overflow. The analysis also yielded a main effect for group, $F(1,44) = 6.50$, $p = .01$, $\omega^2 = .083$ revealing more ipsilateral motor overflow in right-trained subjects.

DISCUSSION

Previous studies (Elliott, 1985; Taylor & Heilman, 1980) have shown that for sequential movement tasks, there is greater transfer of training from the left hand to the right hand than the reverse. This pattern of asymmetry has been used to support models proposing that the left cerebral hemisphere plays a dominant role in the control of sequential movement (Kimura, 1977). In this study, left-hand trained children exhibited improvement on a finger-sequencing task with both their right and left hands, while training was more specific to the hand trained in the right trained group. This pattern of asymmetry in children indicates that the left hemisphere assumes a dominant role in the sequential control of movement sometime before age 10. Why evidence for asymmetric transfer of training was not found in the adult subjects is unclear. Perhaps the task in this study was just too simple and the adult findings reflect a ceiling effect.

Children also exhibited greater contralateral motor overflow and ipsilateral motor overflow than adults. This developmental difference is a common finding and attempts to explain it have centred on CNS maturation and the increasing contralateral control of voluntary movement with age (see Todor & Lazarus, 1985 for review). Both children and adults also exhibited the typical asymmetric pattern of greater overflow from the left hand to the right hand than vice versa. Todor and Lazarus (1985) provide a similar explanation for asymmetric motor overflow as has been proposed by Taylor and Heilman (1980) for asymmetric transfer of training. Both theories regard the left-hemisphere's dominance for the control of sequential movement as the mechanism responsible for the asymmetry. Thus these data also provide evidence for early specialization of motor function.

The similarity of explanations for asymmetric transfer of training and motor overflow are particularly interesting in light of the positive relationship that was evidenced between the two phenomena. Children who evidenced the most positive transfer of training also exhibited the greatest motor overflow. The fact that a positive relationship exists is paradoxical, since a phenomenon (motor overflow) that has been associated with aberrant neurological functioning (Abercrombie et al., 1964; Cohen et al., 1967; Woods & Teuber, 1978) is also associated with the greatest transfer of training between the limbs on a sequential task. Perhaps the appearance of motor overflow may not be as maladaptive as believed.

While cause and effect inferences cannot be drawn from correlational data, the positive relationship between motor overflow and transfer of training in children is troubling for clinicians who use motor overflow as a measure of CNS dysfunction. As well, although there was no reduction in contralateral motor overflow with training, ipsilateral motor overflow results indicate that motor overflow was reduced with practice at a task. This result at least would indicate that clinicians should exercise caution in the use of overflow to diagnose hard signs of dysfunction, since some types of overflow may be related to task efficiency.

Experiment 2

Experiment 2 was designed to further investigate the utility of the motor overflow paradigm in the study of cerebral specialization in both nonretarded and Down syndrome subjects. Transfer of training asymmetries have suggested left-hemisphere control for sequential movement processing in Down syndrome individuals (Elliott, 1985). Since Experiment 1 has indicated a positive relationship between transfer of training and motor overflow, perhaps motor overflow can now be useful in studying Down syndrome persons' unique cerebral asymmetry as well. Besides gathering information on motor overflow asymmetries in Down syndrome persons, Experiment 2 was designed to determine whether Down syndrome individuals exhibited excessive motor overflow compared to the children. Also of interest was whether both groups were able to reduce their motor overflow with conscious effort.

In the present study Down syndrome adults and MA-matched children performed an alternate finger-lifting task. Down syndrome persons would be expected to tap more slowly than the children since Elliott (1985) evidenced poorer performance in Down syndrome subjects compared to nonretarded subjects.

Asymmetries in transfer of training in both nonretarded and Down syndrome groups were examined. An asymmetry for transfer of training in Down syndrome subjects would replicate Elliott (1985). If one is to accept Elliott's (1985) proposals, an asymmetry in the left-to - right direction would reflect the same left-hemisphere control for sequential movement in Down syndrome persons as in the nonretarded. As well, an asymmetry in transfer of training for nonretarded children younger than those in Experiment 1 would indicate even earlier lateralization for the control of sequential movement.

The study of hand performance variability would also provide further insight into cerebral specialization in Down syndrome persons for movement control by replicating previous work examining tapping variability. Todor and Kyprie (1980) contended that decreased right hand variability seen in the nonretarded, represents the sequential processing mode of the left hemisphere. Elliott et al. (1986) also found greater variability in the left hand compared to the right hand in both Down syndrome and nonretarded subjects. This, once again, would suggest left-hemisphere control of sequential movement in Down syndrome persons.

In regard to motor overflow, Down syndrome subjects were expected to exhibit greater motor overflow than the children since excessive amounts of motor overflow have been evidenced in mentally retarded persons (Abercrombie et al., 1964; Cohen et al., 1967). The asymmetry in motor overflow was expected to be in the typical left - to - right direction as is the asymmetry for transfer of training in both nonretarded and Down syndrome groups. The direction of motor overflow asymmetries in special populations is still under dispute, however, based on the previous positive relationship found between transfer of training and motor overflow, one would predict the direction of the asymmetries to be similar.

A final purpose of Experiment 2 was to explore the ability of nonretarded children and Down syndrome adults to consciously inhibit their motor overflow. Based on work by Abercrombie et al. (1964), Cohen et al. (1967), Szatmari and Taylor (1984), Down syndrome subjects were expected to have more difficulty than the children in inhibiting their motor overflow since studies show inhibition difficulties in subjects with possible neurological impairment.

METHOD

Subjects

Subjects were 24 right-handed, adult males with Down syndrome (MA = 5 yrs, 6 mos, SD = 1 yr, 11 mos; CA = 26 yrs, 10 mos, SD = 5 yrs, 1 mo) and 24 right-handed nonretarded, male children matched for MA (CA = 6 yrs, 3 mos, SD = 1 yr, 6 mos).[4] The Down syndrome subjects were either students from a local school for the trainably mentally retarded or various area workshops. Mentally retarded subjects were not able to be stratified or excluded according to their type of Down syndrome, but since 90% of all cases of Down syndome are of the nondysjunction variety and all subjects were randomly assigned to two training groups, it was felt that any effects of genetic diversity were minimized. The children were students from either the campus day care centre or local separate schools. The MA data were collected on the Down syndrome subjects immediately after participation in the study using the Peabody Picture Vocabulary Test - Revised. The nonretarded children who participated in the study had no known developmental deficits.

Apparatus

The apparatus consisted of 8 vertical microswitches (Armaco SB 1231), sensitive to 16 grams of weight. The microswitches were mounted on two wooden boards (4 switches/ board) and aligned so that the 4 fingers of each hand could be comfortably placed on each switch. The microswitches were interfaced with an Apple II+ microcomputer.

Procedure and Design

Prior to the experiment, the subjects hand dominance was determined following the same procedure and criteria as Experiment 1. Subjects were told to begin each trial with all eight keys depressed and upon a computer-generated auditory signal, to begin alternately lifting the index and second fingers on one hand as fast as possible while keeping all other switches depressed and forearm flat on the table. A two-finger task was used in this experiment because pilot studies revealed that a four-finger sequencing task as in Experiment 1 was too difficult for the Down syndrome subjects. Each trial lasted 15 seconds. Any movement occurring in the inactive hand or in the third or fourth finger of the performing hand were considered contralateral and ipsilateral motor overflow respectively. Each subject performed 2 pre-training trials with each hand alternating hands from trial- to-trial. The starting order of hand use was counterbalanced across subjects. Subjects did not receive feedback during the pre-training phase.

During the training phase, half of the subjects trained with their right hand and half of the subjects trained with their left hand with feedback concerning the number of lifts given after each trial. Subjects then performed two post-training trials per hand with no feedback given. Finally, the subjects were informed of the unintended lifts occurring in the other fingers and were instructed to try to consciously inhibit any finger movement other than that occurring in the primary task. Two additional trials were given for each hand with no feedback given.

The design was a 3 (Training Group) x 2 (Etiology) x 3 (Time: pre, post and conscious) x 2 (Hand) mixed design with repeated measures on the last two factors. Active hand performance was measured by 3 dependent variables including, mean number of lifts, errors per hand and SD of the inter-sequence interval.[5] Two other factors, contralateral and ipsilateral motor overflow were both measured by mean number of lifts and average time per lift.[6]

RESULTS

Performance (Pre-Post)

Active Hand

Active hand performance (*M* number of lifts/finger) was analyzed in a 2 (Etiology) X 2 (Training Group) X 2 (Hand) X 3 (Time) ANOVA with repeated measures on the last two factors. The analysis revealed main effects for hand, $F\ (1,44) = 8.15$, $p = .006$, $\omega^2 = .005$ and time, $F\ (2,88) = 43.85$, $p < .001$, $\omega^2 = .10$. As expected, subjects performed better with their right hand than their left hand. Post hoc tests of the effect for time revealed an improvement in the number of lifts performed by all subjects with the pre-training performance being significantly poorer than post-training performance and during conscious inhibition. The latter two phases did not differ.

An interaction between hand and training group, $F\ (1,44) = 4.11$, $p = .046$, $\omega^2 = .002$, indicated that in right-trained subjects their right hand was significantly better than their left hand although in subjects who trained with their left hand, both hands performed equally well.

The analysis also revealed a significant training group X time X hand interaction, $\underline{F}$ $(2,88) = 7.76$, $\underline{p} = .001$, $\omega^2 = .003$ and an etiology X training group X time X hand interaction, $\underline{F}$ $(2,88) = 5.01$, $\underline{p} = .008$, $\omega^2 = .002$ (see Figure 2). The four-way interaction revealed that in the Down syndrome subjects while there were no differences between the hands prior to training, post-training performance depended on the type of training that subjects received. In Down syndrome subjects who were right-trained, the right hand performed more lifts than the left hand. With left-hand training however, there was no difference between the two hands. This is support for asymmetric transfer of training in Down syndrome persons (Elliott, 1985). During the conscious inhibition condition the right hand performed more lifts than the left hand regardless of whether a subject was left-trained or right-trained. It is not clear why left-trained Down syndrome subjects did so well during conscious inhibition with their right hand. Perhaps, with more training, Down syndrome subjects trained on their inefficient left hand, would have had a right-hand performance pattern similar to the other groups.

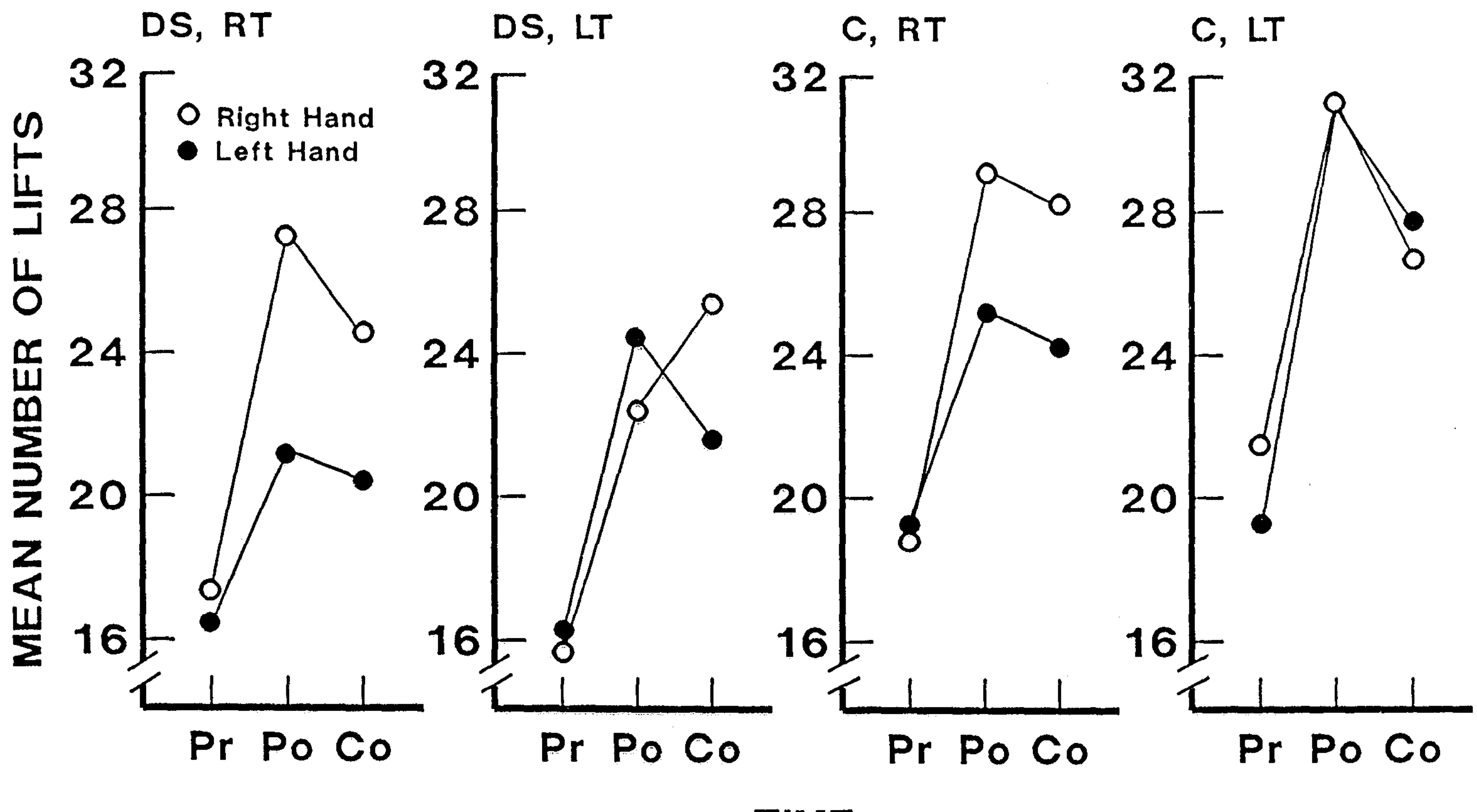


Figure 2. Performance of Active Hand (Mean Number of Lifts) as a Function of Etiology, Hand, Training Group and Time. DS = Down Syndrome, C = Children, RT = Right-Hand Trained, LT = Left-Hand Trained, Pr = Pre, Po = Post, Co = Conscious

As in the Down syndrome subjects, there were no hand differences in the pre-training phase for the children however training differentially affected their performance post-training. Again with right-hand training, the right hand performed better than the left hand but with left-hand training the hands performed equally well. As well, the left hands for the two training groups were different, with left hand performance in the left-trained children being superior. Again evidence is provided for asymmetric transfer of training, this time in a group as young as six years old. In the conscious inhibition condition the right hand remained superior to the left hand when the children received right-hand training and no difference in the hands of the left-trained group was exhibited. As expected, the left hand of the left-trained children tapped faster than the left hand in the right-trained children. It also appears (Figure 2) that in left-hand trained children, having to consciously inhibit the motor overflow in the passive hand decreased their performance relative to post-training trials.

The standard deviation (SD) of the interlift interval of the performing hand was submitted to a 2

(Etiology) X 2 (Training Group) X 2 (Hand) X 3 (Time) AVOVA with repeated measures on the last two factors. The analysis yielded main effects for hand, F (1,44) = 6.07, p = .016, ω^2 = .007, and time, F (2,88) = 8.74, p < .001, ω^2 = .03. The left hand (397.74 msec) was more variable than the right hand (344.91 msec). The main effect for time is the result of the post-training trials being less variable than the pre-training trials. While one might expect decreased variability with practice, the influence of consciously attending to the movements of the passive hand increased the variability of the performing hand to pre-training levels (Pre = 440.40 msec, Post = 318.60 msec, Conscious = 354.97 msec).

Interactions between training group and hand, F (1,44) = 5.85, p = .018, ω^2 = .007 and etiology and time, F (2,88) = 2.91, p = .058, ω^2 = .007, were also found. The first interaction was the result of the right hand in the right-trained group (331.93 msec) being less variable than the left hand (436.62 msec) while in the left-trained group, both hands were equally variable (Right Hand = 357.89 msec, Left Hand = 358.87 msec). Contrary to findings of Peters (1976) who examined single finger-tapping, this would indicate that practice can mediate hand differences in variability. The etiology by time interaction was the result of the children decreasing their sequencing variability from pre- to post-training trials (Pre = 459.15 msec, Post = 293.78 msec) while the Down syndrome persons' variability remained unchanged (Pre = 421.66 msec, Post = 343.42 msec). This suggests that children benefit more from the training than Down syndrome persons. Perhaps this finding was attributable to differences between the groups in learning rate.

The errors made in the performing hand were also subjected to a 2 (Etiology) X 2 (Training Group) X 2 (Hand) X 3 (Time) ANOVA with repeated measures on the last two factors. The analysis revealed only a main effect for time, $\underline{F}$ (2,88) = 10.36, $\underline{p} < .001, \omega^2 = .05$ with fewer errors occurring in the pre-training trials (1.71 lifts) compared to the post-training trials (3.01 lifts) and concious inhibition trials (2.97 lifts). The latter two phases did not differ. Obviously, as subjects made more lifts and became faster, they also became more careless and more errors ensued.7

Contralateral Motor Overflow

Parametric statistics were not used on the contralateral motor overflow data because the amount of motor overflow exhibited by most subjects was minimal resulting in extremely skewed distributions. Therefore non-parametric statistics were employed and specific questions tested.

A Kruskall-Wallis analysis was performed on the mean number of lifts per hand to determine which etiology group exhibited more contralateral overflow. The results indicated that the children exhibited far more overflow than Down syndrome subjects, $H = 7.98$, $p = .005$ (Rank Sum: Down Syndrome = 451.00, Children = 725.00). A similar analysis performed on the average time per lift revealed that again, children spent more time with their fingers lifted than Down syndrome subjects, $H = 10.48$, $p = .001$ (Rank Sum: Down Syndrome = 431.00, Children = 745.00). These findings are contrary to expectations since Down syndrome persons, due to their CNS disturbances, were expected to produce more overflow (Abercrombie et al., 1964; Cohen et al., 1967).

The asymmetry in motor overflow was examined using a Friedman ANOVA by Ranks on the mean number of lifts.

In contrast to Experiment 1 and Todor and Lazarus (1986) there was no difference between left and right hands in normals or in Down syndrome persons. A similar analysis of average time per lift also revealed no hand differences for Down syndrome subjects.

Motor overflow (*M* number of lifts) also appeared to be independent of training. The Kruskall-Wallis test revealed that there were no differences between left-trained and right-trained groups. There were also no training group differences in average time per lift for Down syndrome or nonretarded subjects when the groups were examined separately.

A Friedman ANOVA by Ranks was performed on mean number of lifts to determine whether contralateral motor overflow decreased with training. Neither Down syndrome nor nonretarded subjects exhibited any change in overflow with time. A similar analysis was performed on the average time per lift. Again there was no difference in contralateral overflow in Down syndrome persons or normals.

Correlational Analyses

Correlational analyses were conducted to investigate the relationship between transfer of training and motor overflow in children and Down syndrome adults. As in Experiment 1, improvement scores were calculated by subtracting pre-training scores from post-training scores in the performing hand. The analysis did not reveal a correlation between overflow and transfer of training in Down syndrome subjects who were left-hand trained. There was, however, a significant positive correlation between transfer of training and pre-training motor overflow in right-trained Down syndrome subjects, $r(10) = .78$, $p < .01$. Thus the greatest transfer of training was exhibited by subjects who evidenced the most contralateral overflow. Two separate correlational analyses were performed on the children's contralateral motor overflow (mean number of lifts) and transfer of training. Unlike Experiment 1, there was no relationship in children except a significant positive correlation between pre- and post-training motor overflow in left-trained children, $r(10) = .74$, $p < .01$.

Ipsilateral Motor Overflow

Ipsilateral motor overflow scores (M number of lifts) were subjected to a 2 (Etiology) X 2 (Training Group) X 2 (Hand) X 3 (Time) ANOVA with repeated measures on the last two factors. The analysis revealed main effects for etiology, $F = 20.41$, $p <$

.001, ω^2 = .16 and time, F = 13.17, $p < .001$, ω^2 = .04. As in contralateral motor overflow, there was more ipsilateral motor overflow exhibited in the children. Post hoc analysis of the effect for time indicated that during conscious inhibition less overflow was exhibited than either pre or post conditions while the latter two did not differ.

The interaction between etiology and time, F (2,88) = 8.76, $p < .001$, ω^2 = .03, provides further insight into ipsilateral overflow. The decrease in overflow was due mainly to the performance of the nonretarded subjects (M number of lifts: Down Syndrome pre = 2.58, post = 2.16, conscious inhibition = 1.63; Children pre = 6.23, post = 8.76, conscious inhibition = 4.25). The nonretarded subjects had significantly more ipsilateral overflow from pre to post conditions, however during conscious effort, were able to reduce their overflow to below that in both post- and pre-training phases. Thus, when made aware of the ipsilateral overflow children were able to reduce it. The Down syndrome subjects' overflow remained unchanged across conditions. There were no significant results revealed by a four-way ANOVA on the average time per lift for ipsilateral motor overflow.

Training Phase

Performance

The training performance was analyzed in a 2 (Etiology) X 2 (Training Group) X 3 (Block) ANOVA with repeated measures on the last factor. As in Experiment 1, one block of trials consisted of the mean of four training trials. This analysis yielded a main effect for block, $F\ (2,88) = 29.50$, $p < .001, \omega^2 = .03$ which was the result of gradual improvement in the number of lifts per block with each block being significantly different from the others. Two separate three-way ANOVA's for standard deviation of the interlift interval and performance errors did not reveal any significant findings.

Contralateral Motor Overflow

A Kruskall-Wallis analysis was performed on contralateral motor overflow scores (M number of lifts) during the training phase to determine whether Down syndrome and nonretarded subjects differed in contralateral motor overflow. The analysis revealed that as in the performance phase, normals showed significantly more motor overflow, $H = 11.16$, $p = .001$ (Rank Sum: Down Syndrome = 426.00; Children = 750.00). A similar analysis on the average time per lift revealed that normals spent more time with their fingers lifted than Down syndrome subjects, $H = 5.25$, $p = .02$ (Rank Sum: Down Syndrome = 477.00, Children = 699.00).

The asymmetry in contralateral motor overflow during training trials was examined using a Kruskall-Wallis analysis. Separate analyses of Down syndrome and nonretarded subjects revealed that there was no significant difference between the right and left hands in normals, however Down syndrome subjects exhibited more motor overflow when the left hand was performing than when the right hand was active, $H = 8.50$, $p = .003$ (Rank Sum: RH = 99.50, LH = 200.50). This asymmetry is in the direction found by previous researchers with the nonretarded subjects (Todor & Lazarus,1986). When collapsed across etiology, there still remains an increased amount of overflow exhibited during left-hand performance as compared to the right hand, $H = 4.25$, $p = .04$ (Rank Sum: RH = 488.00, LH = 688.00).

Similar analyses performed on contralateral overflow scores (average time/lift) revealed that there was no difference in the amount of time spent with fingers up between right and left hands in nonretarded subjects. However, Down syndrome subjects spent more time with their fingers raised in the right hand as compared to the left hand, H = 11.21, p = .001 (Rank Sum: RT = 92.00, LT = 208.00). When collapsed across etiology, the right hand still spent more time up than the left hand, H = 5.00, p = .02 (Rank Sum: RT = 479.50, LT = 696.50).

Four separate Friedman ANOVA by Ranks were used to determine whether contralateral motor overflow decreased across blocks. The results revealed no significant decrease in motor overflow between hands for Down syndrome persons or nonretarded children in either mean number of lifts or average time per lift.

Ipsilateral Motor Overflow

Ipsilateral motor overflow scores (M number of lifts) were subjected to a 2 (Etiology) X 2 (Training Group) X 3 (Block) ANOVA with repeated measures on the last factor. Only a main effect for etiology was found, F (1,44)= 9.12, p =.004, ω^2 = .12. Nonretarded children again evidenced more ipsilateral overflow than Down syndrome subjects (M number of lifts: Down Syndrome Adults = 4, Nonretarded Children = 9.08). A similar analysis of the average time per lift did not yield any significant effects.

DISCUSSION

In the present study, a rapid unimanual tapping task was employed to investigate transfer of training, motor overflow, and their asymmetries in Down syndrome adults and young children. The results of Experiment 2 replicate the findings of previous researchers. Elliott (1985) found that both Down syndrome adults and nonretarded adults exhibited transfer of training asymmetries in a left- to - right direction and the present study extended his work to reveal an asymmetry in children as young as six years old. Thus, the asymmetry in transfer of training appears to be a robust phenomenon that may well reflect a left-hemisphere specialization for the organization and control of sequential movement.

The existence of a four-way interaction in the performance data is due mainly to the performance of the left-trained Down syndrome subjects in the conscious inhibition condition. In all other groups, the hand superiority found in the post-training phase remained in the conscious inhibition phase. In left-trained Down syndrome subjects the right-hand performance surpassed left-hand performance during the conscious inhibition phase.

The prediction of a slower tapping rate in Down syndrome adults compared to the children was not confirmed by Experiment 2. Both nonretarded children and Down syndrome adults improved with practice and performed faster with their right hand, but the two groups did not differ in the number of lifts performed. This is contrary to Elliott (1985) who found that Down syndrome subjects tapped more slowly than an adult control group and did not exhibit the right-hand tapping superiority shown by the nonretarded adults. These results would seem to indicate that performance was related to mental age since Down syndrome subjects' performance was inferior to nonretarded adults but equivalent to children of the same mental age.

As expected, the right hand exhibited less variability than the left hand which, may reflect the left-hemisphere's role in sequential movement organization (Todor & Kyprie, 1980; Todor, Kyprie & Price, 1982, Elliott et al., 1986). Both the Down syndrome and nonretarded subjects become less variable with practice. When consciously inhibiting motor overflow, however,both groups' performance dropped to pre-training levels of variability. Although consciously attending to the involuntary movements does not affect the number of lifts performed by the active hand, it does create increased variability in both hands. Thus there appeared to be a trade-off where more attention devoted to decreasing motor overflow affected the primary task by causing more variability in performance. Analysis of errors occurring in the performing hand revealed that as subjects became faster, they also became more careless and more errors ensued.

In the examination of contralateral motor overflow, it was predicted that Down syndrome subjects would exhibit more motor overflow than children based on research evidencing greater motor overflow in special populations compared to control subjects (Abercrombie et al., 1964; Cohen et al., 1967). Examination of the contralateral motor overflow analyses revealed greater contralateral motor overflow in the nonretarded children compared to the Down syndrome subjects. This surprising finding could mean that motor overflow is related to maturational status and/or experiential factors, and not strictly neurological impairment. However, there are other differences between the groups which could account for the differences such as attentional differences.

An asymmetry in contralateral motor overflow in the typical left- to - right direction for the children was predicted based on research that has shown this asymmetry in children (Todor & Lazarus, 1985, 1986). One might also predict a similar direction of asymmetric motor overflow in Down syndrome persons since Experiment 1 confirmed a positive relationship between motor overflow and transfer of training. As well, Elliott's (1985) transfer of training study found asymmetric transfer of training for Down syndrome persons in the same direction as asymmetric motor overflow. Nevertheless, the results indicated asymmetric motor overflow in the typical direction for Down syndrome subjects in the training phase.

The direction of the asymmetry in the Down syndrome subjects is consistent with Todor and Lazarus (1986), who found asymmetric motor overflow in nonretarded eight year-olds. Perhaps the younger age of the children in Experiment 2 compared to those in Experiment 1 and in the study by Todor and Lazarus (1986) could account for the lack of asymmetry in the children. Although children of six years exhibit contralateral motor overflow, perhaps their maturational level does not allow sufficient lateralization, which researchers believe is responsible for the asymmetry (Todor & Lazarus, 1985). Recently, Lazarus, Todor and Varney (1986) observed asymmetric motor overflow in a group of six year old boys and girls. Since, between the ages of 6 to 8, there is approximately a two year difference in maturational status between boys and girls of the same age (Waber, Mann & Merola, 1985), the boys and girls in the Lazarus et al. (1986) study were not maturationally equilavent. Younger and older males and females are, however, equivalent in maturational status. Perhaps the six year-olds in the present study did not exhibit an asymmetry because they were simply too young.

Based on work examining special populations and their ability to inhibit motor overflow, the Down syndrome persons were not expected to be able to inhibit their motor overflow (Abercrombie et al., 1964; Cohen etal., 1967; Szatmari & Taylor, 1984). This prediction was confirmed in Down syndrome persons however children were able to decrease their ipsilateral motor overflow with conscious effort. Perhaps the Down syndrome adults could not decrease their ipsilateral motor overflow as well because they exhibited so little initially. Thus a floor effect may account for the Down syndrome subjects' inability to decrease their motor overflow.

As evident in Experiment 1, correlation analyses revealed a positive relationship between transfer of training and motor overflow. However in Experiment 1 it was exhibited in children and in Experiment 2, in the Down syndrome subjects who were right-hand trained. In both cases, those subjects who exhibited the most transfer of training were also those who exhibited the most contralateral motor overflow.

GENERAL DISCUSSION

Experiment 1 and 2 investigated motor overflow and interlimb transfer of training in both nonretarded (Experiment 1) and Down syndrome (Experiment 2) persons. A major purpose was to examine the relationship between transfer of training and motor overflow to further understand the nature of motor overflow and the cerebral specialization variables governing motor asymmetries. To study this relationship it was necessary first, to replicate previous work and establish an asymmetry in transfer of training on the sequential tasks employed in both experiments.

Both Experiment 1 and 2 confirm Elliott's (1985) report of greater transfer of training from the left hand to the right hand than the reverse, in both Down syndrome and nonretarded adults. Elliott (1985), following the logic of Taylor and Heilman (1980), suggested that the asymmetry was the product of the left-hemisphere control of movement sequencing. The finding that right-hand training benefited only the right hand while left-hand training benefited both hands, was a consistent finding in both groups of children employed in the present study and the Down syndrome adults. Perhaps a ceiling effect in the nonretarded adults could account for the absence of an asymmetry in this group. Nevertheless, asymmetric transfer of training in a group as young as six years old provides evidence for the early specialization of the left hemisphere for the sequential control of movement in both hands. As expected, greater variability was exhibited during left-hand performance. This was a replication of previous research and is often explained as a reflection of the left-hemisphere's dominance in movement control (Todor & Kyprie, 1980; Todor et al., 1982; Elliott et al., 1986).

The typical left- to - right asymmetry on motor overflow evidenced by previous researchers was replicated here (Todor & Lazarus, 1985, 1986). In Experiment 1, both children and adults had more motor overflow in the right hand during left hand performance than vice versa. Although Down syndrome subjects exhibited a similar asymmetry in Experiment 2, it was unclear why the children did not exhibit this pattern. Todor and Lazarus (1985) explained the asymmetry in terms of the left hemisphere controlling the motor performance of both hands and the right hemisphere controlling only the left hand during complex, sequential movement. This explanation is similar to that of Taylor and Heilman (1980), in explaining transfer of training asymmetries. Thus it appears that motor overflow and transfer of training asymmetries have a common underlying basis.

Although the expected asymmetry in contralateral motor overflow was obtained, the fact that so little motor overflow was shown initially is rather disturbing. Todor and Lazarus (1986) found that the exertion level of the desired movement influenced the occurrence of motor overflow. Their study showed that contraction of the active limb in a clip-pinching task, above 50% of their maximal voluntary contraction, dramatically influenced the amount of overflow exhibited. Perhaps the tasks in Experiment 1 and 2 were too sensitive to elicit much overflow.

Correlational analyses also suggest a similarity between motor overflow and transfer of training since several positive correlations between the two phenomena were found. The positive relationship however, is elusive since it was found in left-trained children in Experiment 1 and in right-hand trained Down syndrome adults in Experiment 2. Nevertheless an interesting paradox exists since both groups showed that more transfer of training was related to more motor overflow. Therefore the link between motor overflow and transfer of training should be explored further since motor overflow may not be as maladaptive as has been suggested (Abercrombie et al., 1964; Cohen et al., 1967; Woods & Teuber, 1978).

The positive relationship between motor overflow and transfer of training invites questions concerning the utility of motor overflow as a diagnostic tool of neurodevelopmental delay. In both experiments, children showed more motor overflow than nonretarded and Down syndrome adults. This finding is contrary to my prediction since Down syndrome subjects were expected to produce more motor overflow based on research linking motor overflow and neurological dysfunction (Abercrombie et al., 1964; Cohen et al., 1967; Woods & Teuber, 1978).

As well, children could decrease ipsilateral motor overflow with conscious effort and by simply having more practice on the task. Thus it appears that factors other than those with a structural basis can influence motor overflow. It should also be pointed out that no subjects were able to reduce their contralateral motor overflow and Down syndrome subjects could not decrease their ipsilateral motor overflow. Szatmari and Taylor (1984) found that children with behaviour problems could not decrease their motor overflow but on the other hand, Cohen et al. (1967) demonstrated that young (9 years old), nonretarded children could inhibit their motor overflow. Perhaps the difficulties in inhibiting motor overflow in the children in Szatmari and Taylor's (1984) study and Down syndrome persons in the present study were not related to neurological status but other factors such as inattention.

Recently, Lazarus et al. (1986) examined the extent to which being able to direct available resources in children influenced motor overflow. Children ranging in age from 6 to 16 years performed a clip-squeezing task. The children received trials with auditory feedback to aid in decreasing their motor overflow, and trials with the auditory feedback removed. The results indicated that the greatest amount of motor overflow was in the 6 year-old group, but all groups were able to decrease their motor overflow with feedback. When the feedback was removed, all the children lost some ability to inhibit their overflow with the most pronounced loss occurred in the 6 year-olds. Lazarus et al. (1986) deduced that neural maturation was not the limiting factor in the children's performance since overflow could be reduced with feedback.

In order to test the notion that the children simply had difficulty in self-directing their resources, the 6 year-olds were categorized into groups based on their performance on the Children's Embedded Figures Test (CEFT) which was believed to reflect the ability to inhibit perceptual cues. Their results indicated that children who had superior performance on the CEFT, could maintain their ability to inhibit overflow without feedback and the others failed. Lazarus et al. (1986) concluded that the developmental trends characteristic of motor overflow are not due to maturational factors but are influenced by the increasing control of attentional processes. These findings suggest that further study of the influence of cognitive processes on motor overflow are required. Meanwhile, clinicians should use caution in the interpretation of motor overflow as an index of hard neurological problems, unless factors related to attention and task efficiency can be ruled out.

In summary, the basis of asymmetric transfer of training and motor overflow may be related to the left-hemisphere's dominance in the organization and control of sequential movement. Thus, the future of asymmetric motor overflow may prove useful in the investigation of cerebral specialization. Motor overflow's utility as a clinical tool, however, should be further researched. The present study indicated that motor overflow follows a developmental course and is therefore potentially useful in examining development and diagnosing developmental delays. Although motor overflow is sensitive to developmental difficulties, caution should be exercised in using motor overflow to diagnose structurally-based problems since research indicates that attention (Lazarus et al.,1986) and learning influence the amount of motor overflow exhibited.

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FOOTNOTES

1. Counters were used only on the second , third and fourth fingers. Equipment constraints did not allow the use of counters for the two index fingers. Mechanical counters were used on the second and fourth finger of each hand, while the third finger utilized an electronic counter. It was impossible to make within hand comparisons since the counters were of two different varieties.

2. Utilization of the right hand first, showed asymmetric overflow to the right hand, however, in a left/right order of hand use, no asymmetry was found.

3. Due to anatomical differences between children and adults, placement of keys may not rectify all biomechanical differences. Therefore main effect differences due to age should be interpreted cautiously.

4. Down syndrome results from an aberration of the 21st chromosome during meiosis. Down syndrome represents 10-15% of the mentally retarded. In 90% of the cases nondysjunction of the 21st chromosome before fertilization is the cause. Down syndrome individuals can be identified by their specific genetic make-up and characteristic physical features. Mosaicism and

translocation are the two other types of Down syndrome which account for 8-10% of the population. Mosaicism results from the nondysjunction of the 21st chromosome after fertilization. Individuals with this type have less pronounced physical characteristics and less severe mental retardation. The translocation type of Down syndrome is caused by the attachment of all or part of one chromosome to all or part of the 21st chromosome. Individuals with this type have typical Down syndrome characteristics and are identifiable only by chromosomal studies (Robinson & Robinson, 1976).

5. Any difference greater than one in the number of lifts between the two fingers was deemed an error. In cases of error, the number of lifts was calculated by averaging the number of lifts between the two fingers and the standard deviation of the slowest finger was used.

6. Unexpected software difficulties did not allow data collection from the fourth finger in each hand.

7. All measures of performance were also submitted to a 2 (Etiology) X 2 (Training Group) X 2 (Hand) X 3 (Time) ANOVA with repeated measures on the last 3 factors. Etiology was used as a within-subject factor since Down syndrome and nonretarded sujects were matched on MA.

These analyses did not provide any additional information and were not reported.

APPENDICES

APPENDIX A

ANOVA Tables

Table 1

Experiment 1 - Active Hand (sec) ANOVA

Source	df	SS	F
Age	1	6858.105	48.749 *
Group	1	183.105	1.302
Age X Grp	1	245.255	1.743
Error	44	6190.049	
Time	1	2570.345	60.087 *
Age X Tim	1	1271.021	29.713 *
Grp X Tim	1	121.922	2.850
Age X Grp X Tim	1	171.574	4.011 *
Error	44	1882.201	
Hand	1	56.876	3.198
Age X Han	1	.521	.029
Grp X Han	1	90.750	5.103 *
Age X Grp X Han	1	18.439	1.037
Error	44	782.539	
Tim X Han	1	4.688	.304
Age X Tim X Han	1	.949	.062
Grp X Tim X Han	1	19.699	1.277
Age X Grp X Tim X Han	1	20.672	1.341
Error	44	678.492	
Total	191	21167.203	

Table 2

Experiment 1 - Active Hand (sec) ANCOVA for Adults

Source	df	SS	F
Group	1	.070	.019
Error	21	78.766	
Hand	1	16.043	7.780 *
Grp X Han	1	6.564	3.183
Error	22	45.362	
Total	46	146.805	

* = $p < .05$

Table 3

Experiment 1 - Active Hand (sec) ANCOVA for Children

Source	df	SS	F
Group	1	20.800	1.098
Error	21	397.839	
Hand	1	32.505	6.919 *
Grp X Han	1	130.021	27.676 *
Error	22	103.349	
Total	46	684.515	

Table 4

Experiment 1 - Contralateral Motor Overflow

(Mean Number of Lifts) ANOVA

Source	df	SS	F
Age	1	1555.533	22.296 *
Group	1	2.637	.038
Age X Grp	1	118.775	1.702
Error	44	3069.789	
Time	1	138.380	2.676
Age X Tim	1	41.720	.807
Grp X Tim	1	5.501	.106
Age X Grp X Tim	1	64.172	1.241
Error	44	2275.195	
Hand	1	202.130	7.219 *
Age X Han	1	2.637	.094
Grp X Han	1	135.845	4.852 *
Age X Grp X Han	1	30.880	1.103
Error	44	1231.914	
Tim X Han	1	3.255	.142
Age X Tim X Han	1	14.355	.628
Grp X Tim X Han	1	1.095	.048
Age X Grp X Tim X Han	1	16.922	.740
Error	44	10006.029	
Total	191	9916.745	

* = $p < .05$

Table 5

Experiment 1 - Ipsilateral Motor Overflow

(Mean Number of Lifts) ANOVA

Source	df	SS	F
Age	1	3070.001	10.254*
Group	1	52.344	.175
Age X Grp	1	853.242	2.850
Error	44	13173.459	
Time	1	127.157	.935
Age X Tim	1	826.057	6.075*
Grp X Tim	1	96.688	.711
Age X Grp X Tim	1	156.331	1.150
Error	44	5982.564	
Hand	1	106.878	2.240
Age X Han	1	74.688	1.566
Grp X Han	1	.574	.011
Age X Grp X Han	1	.204	.004
Error	44	2098.981	
Tim X Han	1	4.305	.259
Age X Tim X Han	1	38.298	2.305
Grp X Tim X Han	1	38.745	2.332
Age X Grp X Tim X Han	1	4.010	.241
Error	44	731.064	
Total	191	27435.562	

Table 6

Experiment 1 - Active Hand (sec) ANOVA in

Training Phase

Source	df	SS	F
Age	1	2332.729	42.240*
Group	1	16.389	.297
Age X Grp	1	7.756	.140
Error	44	2429.898	
Block	2	56.706	4.806*
Age X Blk	2	56.808	4.815*
Grp X Blk	2	1.788	.152
Age X Grp X Blk	2	7.010	.594
Error	88	519.095	
Total	143	5428.180	

* = $p < .05$

Table 7

Experiment 1 - Contralateral Motor Overflow

(Mean Number of Lifts) in Training Phase

Source	df	SS	F
Age	1	565.053	8.425*
Group	1	247.407	3.689*
Age X Grp	1	21.584	.322
Error	44	2951.040	
Block	2	65.983	.999
Age X Blk	2	37.293	.565
Grp X Blk	2	174.079	2.636
Age x Grp X Blk	2	10.287	.156
Error	88	2905.390	
Total	143	6978.000	

Table 8

Experiment 1 - Ipsilateral Motor Overflow

(Mean Number of Lifts) in Training Phase

Source	df	SS	F
Age	1	819.772	4.596*
Group	1	1158.381	6.495*
Age X Grp	1	111.267	.624
Error	44	7847.384	
Block	2	61.346	1.671
Age X Blk	2	19.532	.532
Grp X Blk	2	45.393	1.236
Age X Grp X Blk	2	14.018	.382
Error	88	1615.712	
Total	143	11692.806	

* = $p < .05$

Table 9

Experiment 2 - Active Hand (Mean Number of Lifts)

ANOVA

Source	df	SS	F
Etiology	1	1433.355	2.236
Group	1	95.680	.149
Eti X Grp	1	98.000	.530
Error	44	28201.068	
Hand	1	233.133	8.149 *
Eti X Han	1	8.855	.323
Grp X Han	1	112.500	4.108 *
Eti X Grp X Han	1	7.031	.257
Error	44	1204.856	
Time	2	4128.772	43.852 *
Eti X Tim	2	53.106	.564
Grp X Tim	2	21.023	.223
Eti X Grp X Tim	2	83.078	.882
Error	88	4142.646	
Han X Tim	2	46.193	2.887
Eti X Han X Tim	2	36.429	2.277
Grp X Han X Tim	2	124.130	7.759 *
Eti X Grp X Han X Tim	2	80.172	5.011 *
Error	88	703.951	
Total	287	40803.978	

* = $p<.05$

Table 10

Experiment 2 - Active Hand (SD) ANOVA

Source	df	SS	F
Etiology	1	53086.453	.183
Group	1	48272.496	.660
Eti X Grp	1	83.250	.000
Error	44	12796523.400	
Hand	1	200999.191	6.068*
Eti X Han	1	8000.270	.420
Grp X Han	1	193618.207	5.846*
Eti X Grp X Han	1	30998.484	.936
Error	44	1457358.720	
Time	2	750654.012	8.735*
Eti X Tim	2	250085.613	2.910*
Grp X Tim	2	9453.633	.110
Eti X Grp X Tim	2	15516.926	.181
Error	88	3781248.650	
Han X Tim	2	34518.668	.346
Eti X Han X Tim	2	38280.750	.383
Grp X Han X Tim	2	18990.715	.190
Eti X Grp X Han X Tim	2	5806.441	.058
Error	88	4392075.040	
Total	287	24085570.700	

* = $p < .05$

Table 11

Experiment 2 - Active Hand (errors) ANOVA

Source	df	SS	F
Etiology	1	3.897	.202
Group	1	4.376	.227
Eti X Grp	1	.834	.043
Error	44	850.038	
Hand	1	1.605	.270
Eti X Han	1	3.897	.656
Grp X Han	1	1.188	.200
Eti X Grp X Han	1	1.063	.179
Error	44	261.455	
Time	2	106.002	10.362*
Eti X Tim	2	22.179	2.168
Grp X Tim	2	7.002	.684
Eti X Grp X Tim	2	3.658	.358
Error	88	450.076	
Han X Tim	2	3.960	.388
Eti X Han X Tim	2	24.012	2.350
Grp X Han X Tim	2	2.460	.241
Eti X Grp X Han X Tim	2	3.366	.329
Error	88	449.618	
Total	287	2200.687	

* = $p < .05$

Table 12

Experiment 2 - Ipsilateral Motor Overflow

(Mean Number of Lifts) ANOVA

Source	df	SS	F
Etiology	1	1327.198	20.406*
Group	1	7.752	.119
Eti X Grp	1	13.026	.200
Error	44	2861.721	
Hand	1	20.188	.902
Eti X Han	1	.365	.016
Grp X Han	1	7.110	.318
Eti X Grp X Han	1	20.453	.914
Error	44	984.520	
Time	2	308.326	13.166*
Eti X Tim	2	205.118	8.759*
Grp X Tim	2	1.293	.055
Eti X Grp X Tim	2	8.039	.343
Error	88	1030.370	
Han X Tim	2	16.628	1.079
Eti X Han X Tim	2	31.055	2.015
Grp X Han X Tim	2	9.925	.644
Eti X Grp X Han X Tim	2	14.250	.925
Error	88	678.029	
Total	287	7545.375	

Table 13

Experiment 2 - Active Hand (Mean Number of Lifts)

ANOVA in Training Phase

Source	df	SS	F
Group	1	41.056	.094
Etiology	1	646.219	1.477
Grp X Eti	1	418.305	.956
Error	44	19253.587	
Block	2	744.288	29.450*
Grp X Blk	2	.544	.022
Eti X Blk	2	2.014	.080
Grp X Eti X Blk	2	12.435	.493
Error	88	1110.334	
Total	143	22228.781	

* = $p < .05$

Table 14

Experiment 2 - Ipsilateral Motor Overflow

(Mean Number of Lifts) ANOVA in Training Phase

Source	df	SS	F
Group	1	256.667	2.512
Etiology	1	931.667	9.117*
Grp X Eti	1	102.938	1.007
Error	44	4495.707	
Block	2	6.730	.259
Grp X Blk	2	9.527	.366
Eti X Blk	2	13.032	.501
Grp X Eti X Blk	2	25.319	.973
Error	88	1144.392	
Total	143	6985.833	

* = $p < .05$

APPENDIX B

Correlation Matrices

Table 1

Experiment 1 - Correlation Matrix for Transfer of Training and Contralateral Motor Overflow in Children

	RT		LT		Collapsed	
	Pre	Post	Pre	Post	Pre	Post
Transfer	.019	.372	.603*	-.509	.503*	.162
Pre		.231		.143		.259

Table 2

Experiment 1 - Correlation Matrix for Transfer of Training and Contralateral Motor Overflow in Adults

	RT		LT		Collapsed	
	Pre	Post	Pre	Post	Pre	Post
Transfer	-.287	-.002	-.455	.008	-.315	-.034
Pre		.148		.460		.147

* = $p < .05$

Table 3

Experiment 2 - Correlation Matrix for Transfer of Training and Contralateral Motor Overflow in Down Syndrome Adults

	RT		LT		Collapsed	
	Pre	Post	Pre	Post	Pre	Post
Transfer	.778 *	.109	-.337	-.239	.221	-.077
Pre		.340		.317		.326

Table 4

Experiment 2 - Correlation Matrix for Transfer of Training and Contralateral Motor Overflow in Nonretarded Children

	RT		LT		Collapsed	
	Pre	Post	Pre	Post	Pre	Post
Transfer	.296	-.062	-.502	-.153	-.041	-.108
Pre		.281		.743 *		.367

* = $p < .05$

APPENDIX C

Cell Means

Table 1

Experiment 1 - Cell Means for Active Hand Performance (sec)

Children

	RT			LT	
	RH	LH		RH	LH
Pre	25.69	27.13	Pre	34.08	34.13
Post	14.96	19.90	Post	18.98	17.33

Adults

	RH	LH		RH	LH
Pre	12.67	14.25	Pre	12.83	12.88
Post	10.04	11.94	Post	10.77	11.19

Table 2

Experiment 1 - Cell Means for Active Hand Performance (sec) with Pre-training Scores as a Covariate

		RH	LH
Children	RT	16.01	20.95
	LT	17.93	16.28
Adults	RT	10.07	11.97
	LT	10.74	11.15

Table 3

Experiment 1 - Cell Means for Contralateral Motor Overflow (Mean Number of Lifts)

	Children				
	RT			LT	
	RH	LH		RH	LH
Pre	5.33	9.38	Pre	10.00	9.96
Post	2.79	8.29	Post	6.71	6.35
	Adults				
	RH	LH		RH	LH
Pre	1.33	5.58	Pre	.13	1.13
Post	.63	1.77	Post	.92	1.79

Table 4

Experiment 1 - Cell Means for Ipsilateral Motor Overflow (Mean Number of Lifts)

	Children				
	RT			LT	
	RH	LH		RH	LH
Pre	35.38	33.50	Pre	41.33	40.33
Post	31.02	32.75	Post	31.75	31.90
	Adults				
	RH	LH		RH	LH
Pre	29.96	26.67	Pre	23.17	22.17
Post	31.50	29.40	Post	27.85	23.29

Table 5

Experiment 1 - Cell Means for Transfer of Training and Contralateral Motor Overflow Correlation in Children (Mean Number of Lifts)

	RT	LT	Collapsed
Transfer	7.69	13.35	10.52
Pre	5.30	9.96	7.65
Post	2.81	6.35	4.57

Table 6

Experiment 1 - Cell Means for Transfer of Training and Contralateral Motor Overflow Correlation in Adults (Mean Number of Lifts)

	RT	LT	Collapsed
Transfer	2.23	2.33	2.28
Pre	1.33	1.13	1.23
Post	.63	1.60	1.21

Table 7

Experiment 1 - Cell Means for Active Hand Performance (sec) in Training Phase

		Block		
		1	2	3
Children	RT	20.73	20.27	18.31
	LT	21.65	20.23	18.06
Adults	RT	11.35	11.52	10.90
	LT	12.19	12.29	12.71

Table 8

Experiment 1 - Cell Means for Contralateral Motor Overflow (Mean Number of Lifts) in Training Phase

		Block		
		1	2	3
Children	RT	4.17	7.38	3.19
	LT	10.81	7.38	6.73
Adults	RT	1.00	2.54	1.63
	LT	5.04	2.46	3.21

Table 9

Experiment 1 - Cell Means for Ipsilateral Motor Overflow (Mean Number of lifts) in Training Phase

		Block 1	Block 2	Block 3
Children	RT	35.23	36.67	36.90
	LT	32.53	32.33	32.19
Adults	RT	31.02	35.35	33.38
	LT	25.29	25.79	26.38

Table 10

Experiment 2 - Cell Means for Active Hand Performance (Mean Number of Lifts)

Down

	RT			LT	
	RH	LH		RH	LH
Pre	17.23	16.17	Pre	15.71	16.10
Post	27.46	21.35	Post	22.75	24.81
Consc	24.25	20.40	Consc	25.75	21.65

Children

	RH	LH		RH	LH
Pre	19.00	19.13	Pre	21.98	19.65
Post	29.42	25.83	Post	31.83	31.88
Consc	28.42	24.83	Consc	27.17	28.04

Table 11

Experiment 2 - Cell Means for Active Hand Performance (SD)

Down

	RT			LT	
	RH	LH		RH	LH
Pre	382.65	456.98	Pre	416.40	430.60
Post	319.77	417.67	Post	330.23	306.00
Consc	301.17	349.15	Cons	269.38	312.96

Children

	RH	LH		RH	LH
Pre	435.42	518.10	Pre	482.73	400.38
Post	225.99	394.79	Post	270.00	284.33
Consc	326.54	483.00	Consc	378.58	418.96

Table 12

Experiment 2 - Cell Means for Active Hand Performance (errors)

	Down				
	RT			LT	
	RH	LH		RH	LH
Pre	2.42	1.21	Pre	2.21	1.58
Post	3.79	4.21	Post	2.67	3.13
Consc	2.92	2.58	Consc	3.21	2.21
	Children				
	RH	LH		RH	LH
Pre	1.58	1.67	Pre	1.50	1.46
Post	2.71	2.71	Post	3.13	1.75
Consc	2.75	3.67	Consc	2.75	3.67

Table 13

Experiment 2 - Cell Means for Transfer of Training and Contralateral Motor Overflow Correlation in Down Syndrome Adults (Mean Number of Lifts)

	RT	LT	Collapsed
Transfer	6.02	7.02	6.52
Pre	.21	.21	.21
Post	.38	.25	.31

Table 14

Experiment 2 - Cell Means for Tranfer of Training and Contralateral Motor Overflow Correlation in Nonretarded Children (Mean Number of Lifts)

	RT	LT	Collapsed
Transfer	.71	9.85	8.28
Pre	.92	.75	.83
Post	1.04	1.00	1.02

Table 15

Experiment 2 - Cell Means for Ipsilateral Motor Overflow (Mean Number of Lifts)

	Down				
	RT			LT	
	RH	LH		RH	LH
Pre	3.08	1.88	Pre	2.83	2.50
Post	2.46	1.54	Post	2.08	2.54
Consc	2.63	.83	Consc	1.00	2.04
	Children				
	RH	LH		RH	LH
Pre	6.96	6.67	Pre	5.17	6.13
Post	9.79	8.71	Post	9.92	6.63
Consc	4.19	4.42	Consc	4.25	4.13

Table 16

Experiment 2 - Cell Means for Active Hand Performance (Mean Number of Lifts) in Training Phase

	Down		Children	
	RT	LT	RT	LT
Block 1	22.73	19.08	24.72	26.22
Block 2	25.88	21.11	26.14	29.09
Block 3	29.22	24.22	29.46	32.03

APPENDIX D

Study Limitations

Sample

Caution should be exercised in generalizing the results of these studies beyond the specific populations examined Specifically, only high functioning, male Down syndrome persons were examined. There are some data to indicate that male and female Down syndrome persons exhibited different patterns of cerebral specialization (Elliott et al., 1987). As well, specific subjects were chosen more on the basis of convenience than their similarity to Down syndrome persons on variables such as socio-economic status, experiential background etc.

Overflow Measurement

The task employed may not have been sufficiently difficult to elicit motor overflow in the adults, thus accounting for the observed floor and ceiling effects. Although another task may elicit more motor overflow, the present studies were constrained by the examination of transfer of training asymmetries and performance on a sequential task.

Statistical

Due to the number of dependent variables and analyses, there is an experiment-wise probability of greater than .05 of committing a Type 1 error.