Sequence Comparison Methodology for the Analysis of Movement Patterns in Infants and Toddlers With and Without Motor Delays

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In an attempt to quantify the theoretical construct quality of movement, a set of measurable constructs were identified by subject matter experts, and a scale (the Toddler and Infant Motor Evaluation [TIME]) incorporating those constructs was developed and pilot tested. Sequence comparison data analysis methodology was examined for its applicability to examining series of movements. The study sample consisted of randomly selected children from a pilot edition of the scale. Because research indicates that specific individual positions cannot provide an accurate indication of the normalcy or dysfunction of the motor performance of infants and toddlers, this study researched the ability of series of movement positions in each of five postures (prone, supine, sit, quadruped, and stand) to discriminate between normal and atypical motor development. It was hypothesized that children with motor delays would demonstrate different sequences of movements than children without motor delays. The findings confirmed the hypothesis. Because in this sample there was a significant difference in the performance of children with developmental delays in motor abilities compared with that of children who had normal movement abilities. Children with motor delays had poorer mobility, which was characterized by fewer transitions between movement patterns than children with normal motor abilities.

Traditional methods for examining movement abilities of infants and toddlers do not provide enough detailed information for the occupational therapist or physical therapist who wishes to examine quality of movement in young children. Typically, they focus on motor milestones, reflexes, and other elements of motor behavior, and analyze only specific units of data, rather than sets of data in sequence. Such methodology cannot capture the complexity of the construct quality of movement.

Unit Level of Analysis

The unit level of analysis conceptualizes a motor act as a series of actions that are carried out in an arbitrary sequence (Fetters & Todd, 1987; Roberton, 1984; Roberton, Williams, & Langendorfer, 1980). Numerous examples of this type of analysis exist in the literature. In the work of Clark, Whitall, & Phillips (1988), the complex construct coordination was broken into smaller units of behavior consisting of analysis of temporal and distance relationships between the limbs during walking. In the work of Roberton and colleagues (Roberton, 1984; Roberton, Williams, & Langendorfer, 1980), walking was broken down into smaller intra-task sequences consisting of leg action, trunk action, and arm action. In both examples, the researchers attempted to understand a complex set of individual movements that together compose meaningful motor activity by reducing the movements to small units of motor phenomena.

Other examples of using unit analysis to quantify or describe quality of movement can be seen in kinematic analysis, synchronized filming, and evaluation techniques using electromyographs and accelerometers. These techniques are used to obtain detailed descriptive analyses of movement patterns that delineate the spatial and temporal aspects of movement. Areas studied with kinematics include kicking and stepping movements (Heriza, 1986; Thelen, 1983), independent walking (Forsberg, 1985; Thelen & Cooke, 1987), reaching movements (von Hofsten, 1983), and the relationship between communication and arm movements (Dowd & Tronick, 1986). (For discussion see Gowitzke & Milner, 1988).

Quality of Movement Analysis

A different approach to analysis of quality of movement has involved conceptualizing motor behavior as the interrelationship of naturally occurring complex motor behaviors. Frequently, the term quality of movement is invoked to refer to the complex and subtle motor behaviors that provide an index of functional capacity and central nervous system functioning. The contrast between this quality of movement orientation and the unit approach is clear because the unit approach treats movement as a set
of discrete and fragmentary postures or motions to be examined independently without reference to each other, whereas the quality of movement approach advocates for analysis of interrelated clinically relevant data. One examines individual, specific motions and the other examines data between related series of movements.

Some studies of infant motor behavior have emphasized the theoretical importance of quality of movement analysis in understanding motor development (Flewess, 1984; Hay & Reid, 1988) and its potential for detecting developmental problems (Bly, 1983; Chandler, Andrews, & Swanson, 1980; Harris, Swanson, & Chandler, 1984). However, there have been few systematic attempts to quantitatively analyze motor behavior in terms of quality of movement. One such attempt, the Movement Assessment of Infants (MAI) (Chandler et al., 1980), used 4 to 6 point ordinal rating scales to tap qualitative aspects of infant movement (Harris & Heriza, 1987). However, the MAI does not fully operationalize quality of movement, necessitating the addition of clinical judgments to rate qualitative aspects of movement. Other attempts include Haley’s (1987) study of the acquisition of automatic postural reactions in both infants without disabilities and infants with Down syndrome. Another example is provided by the work of VanSant and colleagues (Richter, VanSant, & Newton, 1989; VanSant, 1988a, 1988b), who used a component approach to detail a variety of developmental sequence patterns, for example, rolling and rising to stand from a supine position. The component approach involves the use of descriptions of actions that are then differentiated into 4 or 5 categories that describe different movement patterns, in each of three body regions, invoked to complete the total pattern. Each category is made up of steps that are combined together and labeled as a particular profile.

The diversity of approaches used to analyze quality of movement may be the result of failure within the field to develop an empirical definition of the term. Operational definitions of quality of movement are diverse. Gorga, Stern, and Ross (1985) and Gorga, Stern, Ross, and Nagler (1988) defined quality of movement in three categories: reaction to movement, fixing, and trunk rotation. On the other hand, Case-Smith (1989) defined quality of movement by evaluating components of posture and fine motor control. Another diverse example of use of quality of movement is provided by Ulrich (1988), who defined quality of movement as a comprehensive systems approach in which performance is compared with predetermined criteria and evaluated in an environmental context. The diversity of explanations of quality of movement found in existing literature highlights the need in the field to operationalize this term and partly accounts for the lack of a unified research approach in studying this issue.

This lack of clarity regarding the meaning of quality of movement points to the need for the development of methods to empirically quantify quality of movement. Lawlor’s (1989) survey of pediatric occupational therapists supports this need. She found that 59% of respondents developed and used instruments that they have personally created rather than existing standardized tools; one primary reason found for this practice was that therapists thought that existing tools did not adequately assess quality of movement.

### Analysis of Movement Sequences

Two methods for analyzing sequences of behaviors have been explored with the data in this study, sequential analysis and sequence comparison. The sequential analysis methodology examined the probabilities that certain coded events would precede or follow one another. For example, the conditional probability that a child would roll over (Behavior 1) given that the child has just moved from prone on surface to prone on elbows (Behavior 2) was calculated. The higher the probabilities between strings of events, the greater the possibility that an important sequence has been observed. All possible strings of double and triple sequences of movements were studied and are aggregated elsewhere (Miller, 1991).

In sequence comparison, the methodology used in the study reported in this article, the similarities or dissimilarities among strings of coded events were examined. For example, the similarity between the sequence of actions all children used in rolling over were assessed.

In analyzing sequences of events or behaviors for motor behaviors in young children, an observation system was developed first. A large number of discrete events (e.g., distinguishable human movements or positions) were defined and each event was given a numerical code. Observers were then trained to use the coding system to document a sequence of events or behaviors over a fixed time period (or sample of time periods). The resulting data were sets of numerical codes for each time period.

Although the application of sequential analysis and sequence comparison within the fields of behavioral sciences is relatively new (Sankoff & Kruskal, 1983), they have been used in a diversity of social science fields. Sequential analysis has produced interesting results in a variety of social interactions research (Bakeman & Gottman, 1986; Wampold, 1989), because it affords the researcher a methodology for going beyond the analysis of static variables to the dynamic aspects of behaviors. Thus it makes possible the recording and analysis of data so that the sequential information inherent in the data is illuminated. For example, Bakeman and Brownlee (1980) studied parallel play in preschool children by examining the sequence of behaviors and counting how often each type of play (each code) followed each other code. They focused on studying whether certain transitions characteristic in play, such as onlooker play, functioned as a bridge to other play behaviors, such as parallel play. Other...
er examples of the use of sequential analysis are provided by Gottman (1981, 1983) who studied the social processes involved in how children become friends; Russell and Trull (1986), who used sequential analyses methodology to study the use of language variables in the process of psychotherapy; and Marfo and Kysela (1988) who examined the differences in the quality of interaction between mothers and their children with or without developmental delays. Russell and Trull noted that sequence analysis methodology is particularly suited for answering questions related to "how persons and situations (including other persons) affect each other on a moment-to-moment basis" (p. 18) rather than for analyzing how much variance is associated with persons, situations, and their interactions.

In contrast to sequential analysis, few sequence comparison studies have appeared in the social science literature. An exception is Jackson's (1990) study of problem-solving behaviors in 9th and 10th grade students. He studied how students' thinking and learning about graphs in math is shaped by a specific computer program used in the classroom. Jackson gathered process data, that is, qualitative observations of students during class sessions, to make judgments about the students' thought processes. In a comprehensive study, the relationships between sequences of gathering data and then developing certain problem-solving thought processes were compared. After completing both exploratory and confirmatory studies, he identified recurring patterns in problem-solving skills and the events that triggered the problem-solving behavior.

The purpose of this study was to explore the applicability of sequence comparison analysis to the study of motor behavior patterns of infants and toddlers. It was hypothesized that children with motor delays would demonstrate different sequences of movements than children without motor delays.

Method

Subjects

The sample for this study was selected from 257 children without developmental delays and 133 children with motor delays distributed across 10 age groups included in the third pilot study of the Toddler and Infant Motor Evaluation (TIME), a new diagnostic motor evaluation for young children that is currently being standardized nationwide in the United States. The sample was stratified by age, race, gender, and region. The normal group was defined as children who had no suspected or diagnosed developmental delays, and whose history did not have significant biologic risk factors (such as low birth weight, prematurity, neonatal intensive care, etc.). The children with motor delays (labeled at-risk in this study) were identified by either low test scores (< −1.5 standard deviations below the mean on a standardized scale such as the Bayley Scales of Infant Development: Motor Scale) or by a constellation of significant biological risk factors and designation of motor delay by occupational therapists or physical therapists treating the child. Sample demographics are shown in Table 1.

For purposes of piloting the use of the sequence comparison methodology, a subsample of 30 children were selected at random from the larger sample. Included in the subsample of 30 were 15 children without developmental delays and 15 children with motor delays.

Procedures and Instruments

The TIME has had an extensive history of development prior to this study through three editions. In the first edition, TIME Pilot I, a panel of experts developed a table of specifications for the assessment of motor behavior in infants and toddlers. The subdomains designated for evaluation were Mobility, Stability, Motor Organization, Atypical Positions, Functional Performance, Quality Rating, Component Analysis, and Behavior During Testing. The Mobility subdomain was targeted for the sequence comparison study discussed in this paper (see Figure 1 for depiction of subdomains included in the TIME).

In TIME Pilot I, an initial pool of items and the administration procedures for the TIME were developed. Expert review and field testing culminated in revisions of the TIME and subsequent implementation of TIME Pilot II, which involved field testing the revised TIME. The results and expert consultation led to a new taxonomy detailing constructs for assessing quality of movement. This taxon-

### Table 1

<table>
<thead>
<tr>
<th>Age (months)</th>
<th>Gender</th>
<th>Ethnicity</th>
<th>Geographic Region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>M</td>
<td>C</td>
</tr>
<tr>
<td>Without delays</td>
<td>257</td>
<td>22</td>
<td>21</td>
</tr>
<tr>
<td>With delays</td>
<td>135</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>390</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>8%</td>
<td>7%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Note: Gender: F = Female; M = Male; Ethnicity: C = Caucasian, B = Black, H = Hispanic; Region: F = East, C = Central, W = West, S = South, Ca = Canada.
Motor domain taxonomy.

Figure 1. Motor domain taxonomy.

For TIME Pilot III, 25 pediatric occupational therapists and physical therapists were trained in TIME test administration and scoring, and sampling procedures. All examiners were certified in neurodevelopmental treatment or administration and interpretation of the Sensory Integration and Praxis Tests and had at least 10 years of pediatric experience.

Before initiating each testing session, the examiner completed a behavior checklist to determine whether the child's performance would be affected by fatigue or illness. Direct evaluation of the child was not initiated if a score indicated nonalert status. The testing session was completed in three parts. During the first part, spontaneously occurring movement behaviors were observed during play. The parent placed the child in a series of starting positions (supine, prone, sit, quadruped, and stand). The recording form had pictures and code numbers for each variation of each position (see Figure 2). Subjects were observed for 20-sec periods. The examiner circled the number under each position observed, indicating the order in which the child assumed the position. Thus, each data record consisted of a set of code numbers, representing six positional variations, recorded in the order of occurrence. Each data record was therefore a line of an event-sequential data file consisting of simple codes for each position in order of occurrence.

For example, in Figure 2, the scores are 02, 14, 27, 28, 34, 10, indicating the order in which the positions were assumed. First the child began in supine (02), then rolled to prone (14), and ended up in prone on extended elbows (27); after shifting weight from arm to arm (28), the child rolled back to supine (34), and finished the 20-sec session in supine playing with feet (10). Atypical variations in positions were also recorded (see Figure 3). These were clinically rated as mild (1), moderate (2), or severe (3) when observed at any time during the test session.

The second part of the session rated performance on numerous unique motor organization (motor planning) tasks elicited by the parent, such as kicking a rolled ball. The examiner observed and recorded scores and prompted parents when cueing was needed to complete the item. The tasks in this section assessed individual differences in coordination, balance, locomotion, motor control, and postural control.

The third part of the test session consisted of a detailed interview of the child's parent to determine the functional performance abilities of the child. Open-ended narrative techniques were used to establish the parent's perception of self-care, self-control and mastery, inter-
actions and relationships, and functioning in the community.

Data Analysis

Only the data analysis from the first part of the study is reported in this paper. We analyzed the sequences of movements using a method derived from the work of Sankoff and Kruskal (1983) and Sellers (1974). Within each 20-sec trial, examiners coded six positions observed. Some infants demonstrated significant movement from the original position (e.g., 02, 14, 27, 28, 34, 10) (see Figure 2). Other infants remained in fixed positions (e.g., 02, 02, 02, 02, 02, 02) during the 20-sec interval (see Figure 2).

Sellers (1974) developed a computer algorithm for comparing sequences through the calculation of a dissimilarity score. The score is a count of the number of dissimilar elements in two sequences. An example of two coded sequences is as follows:

Child A: 10 12 29 31 82 83
Child B: 10 10 10 10 10 10

Dissimilarity = 10

Only the initial 10 is identical in these two sequences, so the number of similar elements is 2 and the number of dissimilar elements is 10. This dissimilarity score can then be calculated for all possible pairs of subjects to produce a dissimilarity matrix. For example, if 15 infants were observed, a 15 by 15 matrix of dissimilarity scores could be calculated so that all infants are compared with each other in terms of the dissimilarity of their movement sequences.

In another example given below, the dissimilarity score is 4 because the first codes match (10), and the movements coded “12” also match after the extra “10” is deleted in the second sequence:

Child C: 10 12 29 31 82 83
Child D: 10 10 12 23 23 23

Dissimilarity = 8

In the present study, all sequences were of equal length.

As suggested by Jackson (1990), the matrix of dissimilarity scores for this sample was then subjected to multidimensional scaling (Davidson, 1983). Multidimensional scaling (MDS) is the method used to analyze the dissimilarity scores once they have been collected. MDS was used in this study because it does not assume linear
relationships between variables.

In this study, the sequence comparison method of Sellers (1974) was applied to the coded movement data on 30 children from the TIME Pilot III sample, with a computer program developed by the second author. A 30 by 30 dissimilarity matrix was calculated and input (Wilkinson, 1987; Guttman, 1968). The MDS analyses were conducted for each of the five initial positions (supine, prone, sit, quadruped, and stand).

Results
A statistical measure of the degree of separation between the children with motor delays and children without developmental delays in the MDS analyses is the Guttman (1968) coefficient of alienation. The smaller the value of this coefficient, the greater the separation between groups. The coefficients of alienation were .180 for Quadruped, .191 for Supine, .242 for Prone, .260 for Stand, and .269 for Sit.

Plots of each solution, showing the spatial location of each subject in two-dimensional space, were inspected. In the majority of analyses the children with motor delays clearly separated from the children without developmental delays with only a few exceptions (see Figure 4).

One example of a typical sequence demonstrated by children with motor delays included failing to maintain the quadruped position (e.g., 82, 82, 23, 23, 23, 23, which is regression to a prone position). The typical movement pattern for children without developmental delays included a good quadruped position followed by movement to sitting or standing (e.g., 83, 85, 91, 63, 64, 65). Inspection of other positions revealed a strong trend toward the sequences of children with motor delays being characterized by less movement and more stationary postures. Starting the child in the quadruped or supine position appeared to produce the greatest differentiation between children with motor delays and children without developmental delays.

Discussion
Sequence comparison methodology was found to be useful in discriminating between children who have motoric developmental delays and those without motor delays. Children with motor delays are typically characterized by
perseverance or lack of change in motor positions compared with children who have normal motor development. Inspection of the sequences of movements from the quadruped and supine positions, particularly, were predictive of delay status if the child did not show a variety of movements from these basic positions during any of the 20-sec observation periods. The predictive value of observing the child in quadruped and supine was lower than that of observing the child in prone, sitting, or standing positions.

Further, we found that the methodology of motor-sequence comparison can be adapted to create a scoring system for a motor assessment. The typical sequences of children without developmental delays for selected positions (supine, prone, quad, and sit) were identified and their differentiation from typical sequences of children without delays was verified. The typical no-delay sequences were then stored in a computer-scoring program, thus sequences of all children tested in the future can be compared with these target sequences. The higher the dissimilarity score of a given child when compared with these typical no-problem sequences, the more delayed the child would be. In future research, the sum of these dissimilarity scores will be examined as an at-risk indicator and then be subjected to numerous statistical analyses.

**Broader Implications of Methodology for Other Occupational Therapy Research**

Sequence comparison methodology is well suited to many of the questions studied in occupational therapy research. It can be used to evaluate behaviors that are dynamic, process-oriented, and sequenced in time, as well as the relationship between sets of variables. Sequence comparison also has relevance for the study of clinical decision making. Given a particular client behavior, what should the intervention be? Given a particular intervention, what is the result demonstrated by the client? Sequence comparison can provide data on the relationship of behaviors between the client and the therapist.

Evidence is accumulating regarding the usefulness of both sequence comparison and sequential analysis for understanding complex behaviors (Allison & Liker, 1982; Wampold, 1984). New methodologies are being developed to make sequential analysis data more meaningful, including tests for the significance of differences between events across whole sets of data (Gottman, 1979); tests for determining power (Budescu, 1984; Wampold, 1984); tests for ascertaining the presence of cyclicity in events (Allison & Liker, 1982; Gottman, 1979); and methods for determining latent structures in sequential events (Dillon, Madden, & Kumar, 1983).

The recommendation of Russell and Troll (1986) seems relevant to the current state of occupational therapy research using this methodology: "What degrees of change are associated with therapeutic processes perhaps ought to be assessed first in replicable series of descriptively oriented single-case studies, so that the effects of interest at the molecular level are not washed out by between group designs" (p. 19). After these descriptive studies with small numbers, additional studies with
larger numbers should be generated so that the results
can be further generalized.

Expanding the knowledge base of occupational therapy with regard to the study of sequence analysis methodologies will provide occupational therapists with another methodology that may be useful in answering complex topics related to series of behaviors. The use of new and sophisticated research technologies will help overcome current limitations in data analysis procedures. Occupational therapists will then be able to provide even more meaningful, data-based contributions to complex constraints related to research in human development and occupational performance.

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