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LONGITUDINAL RESEARCH OF MOTOR DEVELOPMENT - THE POSSIBILITY OF APPLYING DIFFERENT STATISTICAL METHODS

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SUMMARY

Motor development is a very complex process and two research designs are generally used to study it. These are cross-sectional studies and longitudinal studies. Longitudinal researches are very important because they allow us to identify cause and effect relationships between various factors that influence development. Also, by applying such designs, we discover the dynamics of the complexity of those relationships. This paper analyzes longitudinal researches of motor development with a focus on the application of different statistical methods in these studies. Partial research and the use of a statistical method without multifactorial data analysis are not sufficient to define the specificities and factors of motor development in children of typical development and in children with developmental disabilities. The choice of research design, along with the selection of adequate statistical methods and techniques for data processing, are of the exceptional importance, because this will produce valid results.

Key words: study design, statistical methods, longitudinal research, motor development

INTRODUCTION

Different research designs allow defining methods and procedures for collecting and analyzing collected information. Research design is used to create an adequate research structure, but also to prove that all parts of the research design work together (Robson, Shannon, Goldenhar, & Hale, 2001). The classification of research design is almost the same for all scientific disciplines. Choosing a specific design caused by the phenomenon that we are studying. Studying the areas of human development, most research findings are based on studies using a cross-sectional design. The focus of these studies are on the developmental differences between different age groups, and these studies ignore the developmental changes that have occurred in individuals. Most researchers believe that these studies cannot be considered as truly development studies, but changes that occur over time in all aspects of development can only be evaluated by longitudinal studies (McCall, 1977; Wohlwill, 1980, according to Schneider, 1993). When it comes to study of motor development, the available research findings indicate that two research designs are in use. The first represents a cross-sectional research and the second a longitudinal research (Sretenović, Nedović, Eminović, 2018). In order to determine cause and effect relationships between various factors, longitudinal studies are needed to fully address the dynamic complexities in such relationships (Chaddock et al., 2012; Wittberg, Northrup, & Cottrell, 2012).

In this paper, the focus will be on longitudinal research.

When it comes to longitudinal research, there are several problems. The first problem concerns the definition of a longitudinal research. The term *longitudinal research* not only describes a single method, but encompasses a wide variety of methods. "The spectrum of methods ranges from single case studies in time-series arrangements to broad-band panel designs including numerous measurement points and thousands of subjects. The only common denominator of longitudinal research is variation of time and repeated observation of a given entity" (Baltes & Nesselroade, 1979, cited in Schneider, 1993: 317).

Longitudinal refers to designs which aim to determine individual development of functions by the assessment of transitions and changes in performance over relatively long periods of time. Here it does not refer to designs aimed at measuring the improvement of performance over time in, for example, a task with 1000 trials, with time as a natural independent variable (Geuze, 1993). Longitudinal research derive its strength from the possibility of analysing developmental data individually. It depends on the goal of the study whether the data are described in terms of individual development or of group development. The individual data are averaged, not according to a time reference such as chronological age but according to the occurrence of some important transition in development (Geuze, 1993). For example, most experimental studies on clumsiness (Cantell, Smyth, & Ahonen, 1994, 2003; Geuze & Börger, 1993) are based on some model of information processing or movement control. In the processing of task relevant information, this information may be provided externally (for example stimuli) or internally (for example proprioception). The experimental approach is process-oriented. It aims to assess specific functions in information processing that seem to be particularly relevant for motor performance.

Scientific interest in the longitudinal approach to ontogenetic development dates back to the XVIII century (Bakes & Nesselroade, 1979, cited in Hopkinsy, Beek, & Kalverboer, 1993), but it has never really become a consistent feature of research in child development. This state of affairs is hardly surprising as the practical and methodological difficulties associated with longitudinal research on human development constitute a formidable barrier. These difficulties (Fletcher & Satz, 1984) are so numerous and persistent that longitudinal research may easily become a rocky road to disillusionment. However, practical problems are not the only nor even the main reasons for the dearth of longitudinal studies on motor development. In no small measure this is due to the nature of prevalent theoretical persuasions in general and the scarcity of clearly articulated concepts in particular. After all, the first research step required is the formulation of theoretically meaningful questions and not, one hopes, the selection of a methodology. The type of longitudinal methodology employed is to a large extent determined by the nature of developmental theory (Hopkinsy et al., 1993).

In the available literature, it is possible to find the following two categories of longitudinal studies on motor development. One category contains studies whose purpose are to chart and to understand the changes with age of particular normal or abnormal sensorimotor functions. These are called individual-oriented. The other category consists of follow-up studies of groups of children who meet particular selection criteria with the aim of finding long-term relationships between group characteristics. These are called group-oriented studies (Touwen, 1993).

Individual-oriented studies deal with changes with age which are thought to be characteristic of certain sensorimotor functions, with a view to explaining the dynamics of development. Somewhat paradoxically, more emphasis is given to the function studied than to the individuals who display that function. Because intraindividual comparisons of particular sensorimotor performances are made over time, and because an attempt is made to attribute changes in performance to developmental properties of the brain, other variables which may affect the developmental process have also to be taken into consideration. The effect of some of these variables on development is already known or can be guessed, for example in the case of diseases of the brain or of the motor apparatus itself, severe malnutrition or deformities. The effects of such variables can be discarded by excluding the subjects who suffer from them. For other variables the effect is either not known or is speculative, and, more importantly, many of these variables cannot be discarded because they are omnipresent (Touwen, 1993).

The basic goals of longitudinal research concern the description and explanation of human development. There are three reasons for describing development: (1) identification of intra-individual changes, (2) identification of interindividual differences in individual change and (3) identification of interconnections among classes of behaviour during development. The analysis of causes of intraindividual change, the analysis of causes of interindividual differences in intraindividual change and the prediction of individual differences in one domain from individual differences in another domain are goals that represent the explanation of the development. Studies illustrating these categories include, for example, longitudinal projects investigating the impact of early risk factors (domain A) and later motor skills (domain B). These studies are obviously longitudinal in perspective, because the same individuals are tested multiple times, but they do not necessarily include aspects of intraindividual change in a particular variable (Baltes & Nesselroade, 1979, according to Schneider, 1993).

We can say that there is a general agreement in the literature which examining developmental characteristics, that two basic types of longitudinal testing can be used to achieve the above goals (Appelbaurn & McCall, 1983).

The basic aspect of a longitudinal research concerns what Wohlwill (1980, according to Baltes, Reese, & Lipsitt, 1980) called a “developmental function”. This is explained as the average value of the dependent variable plotted over time. Typical examples derived from a longitudinal research of motor development include growth curves that relate to the development of speed or physical strength and show continuity versus discontinuity of these variables over time. Another aspect of longitudinal research concerns the issues of individual difference. More specifically, the question here is whether individual subjects maintain approximately the same relative rank ordering within their group at one age as they do at another (McCall, 1977, according to Magnusson, 2015). The question is how stable or volatile individual differences among individuals have remained over time. It should be borne in mind that the issue of stability versus instability of individual differences over time is conceptually independent of the question of continuity with respect to interruption of developmental function:

for example, it is theoretically possible to follow a monotonous, linear increase in the average dependent variable over time with a high degree of instability of individual differences in this variables. More specifically, the fact that a linear increase in motor coordination ability can be found in pre-school age does not exclude the possibility that individual differences in performance may not be preserved at this time interval. Researchers using the longitudinal approach to studying motor development often overlook the fact that developmental function and the stability of individual differences over time represent two separate aspects of the same problem (Schneider, 1993).

Analysis of intraindividual and individual change during the time - statistical methods

In the late 1980s, it was tried to clarify to the general scientific and professional public the existence of myths accompanying longitudinal research. Misunderstanding of longitudinal studies is based on measures of intra-individual change over time. However, this problem is very easy to solve and explain today, because sophisticated statistical tools are used to analyze intra-individual changes. Interpretation of the results of changes in the group analyzes was not a problem, because the same results were obtained by using analyses of variance as well as by applying analyses of variance based on the results of changes that occurred after testing. The problem, then, was in assessing individual changes, because many researchers thought these results were undesirable and unfair. Methodological papers written in defense of intraindividual differences also support this (Rogosa, 1988). The findings are the result of an unbiased assessment and a real change in the individual.

Most recent advances in the statistical theories of hierarchical linear modeling (HLM) provide an integrated approach for the study of various aspects of the individual change. Bryk & Raudenbush (1987, cited in Schneider, 1993) have presented a model that enables the estimation of growth structure, the testing of the reliability of instruments for measuring initial status and changes over time, investigating correlates of initial status and changes occurring, and testing hypotheses about effects theoretically of relevant variables. This model, more precisely the hierarchical linear model, consists of two phases. In phase 1, the observed developmental changes of each individual were conceived as a function of a single curve or growth trajectory plus random errors. In phase 2, the assumption is that the individual parameters that determine an individual growth curve vary depending on certain characteristics of the individual's background or environment (e.g. gender or social status). Regarding model assumptions, it is important to note that both individual outcomes and growth parameters are normally distributed. To facilitate change measurement, HLM generates a common metric of the results data collected at each measurement point. As modeling the growth curve requires that the result data collected at each time point be measured on a common metric so that changes over time reflect growth rather than changes in the measurement scale. Item response theory is used to calculate the logit function which models the logs of ratios of multinomial probabilities.

The hierarchical linear model has some specificities when it comes to studying motor development. HLM provides an integrated approach based on a two-stage hierarchical model. This approach makes it possible to study the growth structure of an individual and to evaluate the statistical and psychometric properties of growth curve collections. It also allows assessing the adequacy of between-subject models by estimating the reduction in the parameters of unexplained variance (Schneider, 1993).

"In addition, HLM can be used (a) to assess the reliability of measures for studying both entry status and change, (b) for estimating the correlation between entry status and rates of change, and (c) for predicting future individual growth. While HLM requires multiwave data, the approach is quite flexible in that the number and spacing of observations may differ across subjects" (Bryk & Raudenbush, 1987, according to Schneider, 1993: 330).

One of the most important advantages of the HLM programme is that it capitalizes on any strengths in the available data; that is, if the individual growth curve estimates are reliable, HLM will weight them heavily. If the individual growth curve estimates are not reliable, the model will rely more on information from mean growth curves that are conditioned on available background data (Schneider, 1993).

Longitudinal research focusing on individual differences is based primarily on the issue of stability and predictability over time. For many years, regression statistical models have been used to describe and explain the longitudinal stability or lability of individual differences in different domains. The model of multiple regression analysis is usually based on correction coefficients or covariance structures. The aim is to predict individual differences in the observed criterion variables from different predictors, which may consist of identical measures estimated in the earlier period or may represent conceptually different variables. One of the basic problems of this approach is that the basic statistical model assumes the independence of the predictor variables. The predictors used in regression analyzes are often highly correlated. As a consequence, evaluation results are often biased. Another disadvantage of this statistical model is that nothing is known about the possible interrelationships between the predictor variables, as they are all treated as having the same explanatory status (Schneider, 1993).

With the introduction of another regression approach, the so-called structural equation modeling (SEM) procedure, which uses latent variables, there have been significant changes in longitudinal studies of motor development (Schneider, 1986 according to Schneider, 1993). Computer programs based on this model have existed since the 1970s (say the Linear Structural Equation Model developed by Jöreskog & Sörbom). Causal modeling and SEM techniques have been used by a growing number of scientists involved in the study of human development and developmental change.

A typical feature of all SEM techniques that use latent variables is the difference between a measurement model and a structural model. While the measurement model defines the relationships between the observed variables and the unmeasured hypothetical constructs that represent the observed variables, the structural equation model (i.e., the causal development model) is used to specify cause and effect relationships among the latent variables. For this reason, the factor analytic approach is used to create latent variables, while the regression approach is used to analyze the structural relationships among latent variables. As the general interest is more in the causal / structural relationships among the theoretical constructs than in the relationships between the erroneous observed variables, the logic behind the difference used in SEM procedures makes a lot of sense. Although SEM techniques that use latent variables can be applied primarily to cross-sectional data, they seem particularly promising when used with longitudinal data (Schneider, 1993). Many authors highlights the following advantages of SEM over traditional regression analysis:

- Verbal theory must be reformulated into a mathematical model that can be evaluated;
- Causal relationships are assessed at the level of theoretical constructs;
- The difference between a measurement model describing the relationships between the observed variables and a structural model describing the interrelationships between theoretical constructs also allows a separate estimation of the measurement errors in the observed errors and the specification errors in the structural part of the model: large specification errors usually indicate that the causal model is not in fully listed and missing theoretically important predictive variables;
- It is possible to distinguish between reliability of measured variables and stability of structural relationships;
- There are several so-called suitability tests that reveal the degree of fit between the causal model and the data to which it applies. Causal models are said to be validated when the goodness-of-fit parameter fits the model between data and data that is better than chance;
- Identical structural models can be specified for different samples (e.g. different age groups or children at risk compared to normal samples) to test the generalization of a given theoretical model;
- Although SEM procedures mainly work on correlation or covariance matrices, intermediate structures can also be considered. This means that in the case of multiple comparisons, the relative mean values in the latent variables over time can also be estimated (Beran & Violato, 2010; Schneider, 1993; Tarka, 2018).

There seems to be widespread agreement that SEM procedures are powerful general tools for analyzing longitudinal data. It seems particularly appropriate in large-scale longitudinal studies of motor development that operate on large sample sizes where researchers typically struggle with a large number of variables estimated at different time intervals. As noted above, the SEM approach incorporates the characteristics of traditional regression approaches but is clearly superior due to its flexibility. This is demanding because researchers are forced to refine their verbal theories and translate them into appropriate statistical models. It is not only possible to evaluate causal models, but to test them; that is, to evaluate their data adequacy. Moreover, the coefficients of convenience for competing causal models can be directly compared. Several problems with SEM procedures have been discussed in the literature (e.g. Alwin, 1988; Martin, 1987; Rogosa, 1988). The availability of these techniques offers great potential for abuse. As pointed out by Alwin (1988), in the absence of a well-defined set of theoretical assumptions, in the absence of valid indicators of theoretical assumptions, in the absence of valid indicators of theoretical constructs, or in the absence of a careful set in the measurement process, these methods can lead to meaningless conclusions, which gives a false impression of importance. This represents one of the major difficulties for a responsible researcher using SEM techniques to evaluate this risk.

HLM and SEM procedures have a wide range of applicability in longitudinal studies that address different aspects of motor development.

Application of statistical methods in longitudinal studies

Connolli & Dalgleish (1989) conducted the study that presents a microanalytical longitudinal approach that focuses on issues of intraindividual change. It contains an interesting, detailed description of the development of spoon use skills in four newborns. In their view, the adequacy of nomothetic developmental approaches to assessing the "average" child is questionable, because aggregate data on all subjects is unclear as to the underlying processes of change. This is the phenomenon that different individuals may take different paths to reach the same endpoint of development. Therefore, the emphasis in this study is on individual development. For each child, information about the various behavioral categories was obtained at an interval of about half a year. These authors decided to analyze the data separately for each child using orthogonal polynomials. This trend analysis approach is well suited for analyzing individual case data because it provides a description of the best fit curve (linear, quadratic, or cubic) for the data. The case analysis approach presented by Connolli & Dalgleish (1989) seems appropriate to describe individual changes over time. However, its most obvious limitation is that the results are difficult - if not impossible - to generate among subjects. Consequently, information on the representativeness of the findings cannot be obtained. This dilemma is solved with the HLM approach because the nomothetic and ideographic dimensions can be combined due to the two-stage characteristic of the model.

As discussed earlier, studies addressing the implications of early risk for later motor development are usually based on large samples of subjects and variables and usually last for several years. As a consequence, they represent potential candidates for the SEM approach. In the study by Largo, Kundu, & Thun-Hohenstein (1993), the primary objective concerned the description of motor development, with a particular focus on issues of variability and stability in normal development, as well as the impact of several pre- and perinatal risk factors on later motor development. This study used data from two samples of about 100 premature births and 100 full-term children to represent the developmental course from birth to school entry. Neurological and motor development during the first two years of life were repeatedly evaluated and minor birth defects were measured at age 5. Furthermore, data representing neurological assessment were collected when children were 4 and 6 years old. It appears that both HLM and SEM procedures can be used in future analyzes of this data. HLM analyzes should be limited to the first two years of the study, where information on neurological and motor development is particularly abundant; that is, based on a total of seven measurement points. SEM models can be applied to link motor and neurological development in the range of 0 to 6 years. Information on pre-, peri-, and postnatal factors can be used to predict minor congenital anomalies. Given that the sample size of each subgroup is not particularly large, infant and child birth data can be aggregated, and the dummy risk variable can be introduced into the model as an explanatory factor. SEM approaches could take this advantage by comparing the structural characteristics of motor development for patterns traced through different decades of this century. Such comparisons of models involving different age groups can provide valuable information about the generality or universality of the findings.

For the one more study, the sample size does not cause problems with SEM procedures. The risk group in this longitudinal study included more than 850 children from birth to the age of nine. In addition, a smaller group of children with typical development was available. Comprehensive assessments were made when children were 5 years old, including tests of intelligence and language skills, concentrations, as well as gross and fine motor performance. Assessments at the age of 9 focused on neurological examinations, including various fine and coarse motor functions, and a comprehensive test for motor impairment. In addition, tests of intelligence, language proficiency, and reading and spelling were performed at that particular age. The authors attempted to explain the results in five criterion achievement (i.e., neurological assessment, motor function, language skill, intelligence, and schoolwork) using logistic regression analysis as a statistical tool. Although this tool is in principle suitable for the type of prediction model inherent in the study design, it is of limited value since it operates on the observed variables and cannot consider more than one dependent variable at a time. The advantages of SEM models seem immediate: (a) the difference between theoretical constructs and the observed variables representing these constructs could lead to a considerable reduction in the (latent) variables involved in structural equation models; (b) a structural equation model can be specified that simultaneously includes all five areas of the criterion, thus allowing the different effects of early risk factors to be assessed on different outcome domains; (c) the same structural equation model can be specified for different risk groups. Based on such an approach, multiple group comparisons can be made to investigate whether different risk groups are the same cause model (Michelsson & Lindahl, 1993).

INSTEAD OF CONCLUSION

In short, this brief illustration of possible applications of the HLM and SEM approaches in the field of motor development has shown that the two procedures can be useful when it comes to explaining normal and abnormal motor performance. This does not imply, however, that these approaches should be conceived as “perfect solution”. Certainly, they cannot make up for poor quality data, careless operationalization of major structures and inappropriate design.

Longitudinal studies are important to fully understand the process of motor development during childhood and how risk factors present at this time affect motor development outcomes. However, there is still little research like this.

To better understand and unravel the independent effects of growth and motor performance, longitudinal study designs are required.

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