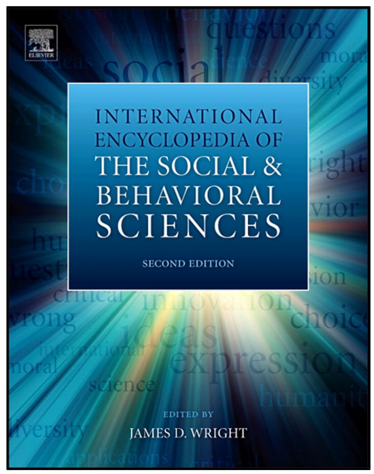

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Cross-Sectional Methodologies in Developmental Psychology

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Abstract

Cross-sectional methodologies are typically adopted in the field of developmental psychology when assessing the impact of developmental age or stage on some cognitive measure. Here, we describe the statistical techniques that form the foundation of cross-sectional studies and illustrate their use through recent examples from the literature. We present both behavioral and brain-imaging work and emphasize the value of cross-sectional designs, with particular reference to studies that explore atypical development and consider change across the life span.

Introduction

A *cross-sectional* experimental design is one that involves taking a snapshot of information at a given point in time. In the context of developmental psychology, this broad approach is typically utilized to assess a cross-section of development, with a variable of interest being studied in children at different ages. For example, a study might measure how children's ability to perform on a memory task varies according to age, while keeping other factors such as socioeconomic status (SES) as consistent as possible. Although usually a design might examine performance across age, it could be across any continuous variable (height, intelligence, or time of day). For example, the measurement of interest could be performance on the memory task as it varies by SES, while age is kept consistent. However, generally speaking, cross-sectional designs in this branch of psychology refer to studies that take age or stage of development to be the continuously varying, predictor measure. In this chapter, we outline the statistical basis and value of cross-sectional designs for developmental psychology, and draw out the limitations and challenges inherent in them. We take specific examples from recent research in the field to illustrate the methodology, each of which takes data collected at a single point in time to understand the processes of change in cognitive systems.

The first systematic analysis of cognitive development arguably came not long after the advent of experimental psychology, when Alfred Binet attempted to measure average cognitive functioning in the domains of sensorimotor processing, language, memory, and logic in children between 6 and 15 years of age. This work resulted in the publication of the first intelligence test in 1905 (Binet and Simon, 1905), and is an excellent example of the early adoption of a cross-sectional methodology. Developmental psychology as a field in its own right did not really gather pace, however, until Jean Piaget's work from the 1930s onward. Piaget made intricate observations of his own children and used them as a basis for his hypothesis that cognitive development is staged and hierarchical (e.g., see Piaget, 1936). His work sparked an explosion of studies addressing cognitive development and, in particular, the underlying mechanisms of change. Developmental psychology is increasingly now thought of as the study of change in cognitive systems, regardless of age; development is a lifelong process.

Variation over developmental time can be recorded in one of two ways: either by studying individuals at different stages of development at one point in time, as discussed here, or by following the same set of individuals over multiple points in time. This latter, longitudinal approach is discussed elsewhere in the current volume. The establishment of statistical measures such as correlation and linear regression, based on the influential work of Karl Pearson at the turn of the twentieth century (see Pearson, 1896), allowed for the formalization of theoretical notions of development. Indeed, theory has driven, and has been driven by, the advance of statistical methods in every area of psychology. Taking once more the example of intelligence research, the establishment of modern notions of the structure of cognition went hand in hand with the development of the statistical technique of factor analysis (see Spearman, 1904). In the remainder of this article, we discuss the statistical measures that have been developed in parallel with the theory and practice of cross-sectional designs in developmental psychology. The addition of each statistical technique will allow us to elaborate from the basic concept of cross-sectional studies to a more complex and powerful set of methodologies. We begin with the roles of correlation and regression.

Correlation

Correlation describes the strength and direction of linear dependence between two variables. The statistic used to describe the relationship is most typically Pearson's r, which is a measure of the covariance of the two variables divided by the product of their standard deviation. The obtained value ranges from -1.0 to 1.0, from a perfect negative correlation, through no dependence between the variables, to a perfect positive correlation. As a measure of the strength of a relationship, r is used as an effect size. With respect to developmental psychology, correlations are frequently used to analyze the relationship either between age and performance on a cognitive measure, or between two cognitive measures at different ages. Cross-sectional designs lend

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themselves well to correlational analysis as the predictor variable tends to be continuous and have a wide range. Here, we will explore some of the applications of correlational analyses in developmental psychology in the context of the relationship between month of birth and academic performance.

Throughout primary and secondary school, there is a significant correlation between children's performance on formal academic tests and their month of birth. This relationship has been established by running cross-sectional studies looking at the outcomes of national curriculum tests sat at ages 7, 11, 14, and 16 in the United Kingdom (e.g., Crawford et al., 2010). Children who are born at the end of the academic year tend to have lower educational attainment than children born at the start of the academic year. Equivalent relationships have been repeatedly found around the world, including in the United States (Elder and Lubotsky, 2008). Month of birth therefore has long-term implications for children's academic achievement and life outcomes as, among other things, it impacts who is likely to finish school and thereby find employment. Readers interested in the details of this relationship and what drives it are directed to Crawford et al. (2013); here, we use it to demonstrate some of the key principles of correlation.

A correlational analysis allows us to probe the nature of the relationship between month of birth and academic achievement. One important question is which aspect of month of birth drives, or mediates, the relationship. The two prime candidate factors are age at starting school and age at which the tests are sat. As these two factors are themselves not perfectly correlated in the United Kingdom, Crawford and colleagues (Crawford et al., 2010) were able to separate out the impact of each. By controlling for each in turn, the authors found that the relationship between month of birth and academic test score is largely driven by, or mediated by, the age at which the test is sat. For the conditions for mediation, see Baron and Kenny (1986) and Holmbeck (1997). Another question that can be answered through a correlational analysis is whether variables exist that impact, or moderate, the strength of the correlation under investigation. In the case presented here, multiple factors could theoretically be moderators. For example, the relationship might ameliorate as children get older, such that age acts as a moderator. In actual fact, the effect of month of birth on academic achievement does lessen over time, but it remains statistically significant to the point of college entry. One paper has found that gender is another moderating variable, with exam results at age 16 from children in the United Kingdom showing that boys born in the summer had the greatest disadvantage and girls in the autumn the greatest advantage (Sharp, 1995).

Correlation, then, can be a powerful tool to establish a relationship between two variables. This method of analysis does have considerable limitations, however, including the assumption of linearity (for nonlinear relationships, growth-curve modeling is more suitable). What correlation cannot tell us is whether the relationship between two variables is causal. This is a difficult problem to overcome without either a longitudinal data set to run time-lagged correlations, longitudinal regression, or the experimental manipulation of variables.

Regression

Simple regression determines the extent to which a value of the dependent (outcome) variable can be predicted based on the predictor variable. This technique differs from correlation in that it tacitly assumes a directional causal relationship between the predictor and outcome variable. The distinction is perhaps clearest when age and cognitive task performance are considered: increasing age indirectly leads to improvements on cognitive tasks, but improvements on cognitive tasks cannot lead to augmentation of age. It is worth noting that changes in chronological age do not directly cause improvements in task performance; age is associated with maturation and experience-dependent learning, which, as aspects of cognitive development per se, may be considered more legitimate direct causes of task performance improvement.

It is common for researchers to use performance on one task to predict performance on another. Note that, according to the logic discussed here, such researchers are tacitly stating that the predictor variable causally determines the outcome variable to an extent. For example, Purser et al. (2012) investigated whether measures of components of Baddeley's (1986) model of working memory predicted the route-learning ability (acquiring knowledge about routes through space) of typically developing children aged 5–11 years. Baddeley's model features both verbal and visuospatial short-term storage components, and a 'central executive' that is concerned with controlling attention (among other things). Verbal short-term memory was assessed with digit span, a task in which participants must repeat back a list of spoken numbers in serial order; visuospatial short-term memory was indexed by Corsi span (Corsi, 1972), in which the participant attempts to reproduce a sequence of spatial locations. The 'executive' component was measured with the Go/No Go task, in which a pseudo-random series of differently colored circles is presented on a computer; participants must press a key as quickly as possible on seeing each circle, unless it is red, in which case they should refrain from pressing the key. Route learning was assessed by the number of errors made in the course of learning a route through a virtual environment maze.

A series of linear regressions indicated that the measures of all three model components – verbal and visuospatial short-term memory and the central executive – were statistically significant predictors of children's route-learning ability. However, one would expect every cognitive function tested to improve with age in this cross-sectional sample and hence be intercorrelated, which was indeed the case. Stepwise multiple regression was therefore used to investigate the independent contributions of each cognitive component to children's route learning.

In forward stepwise multiple regression, predictors are added one by one to the regression model. Due to the fact that multiple regression tests for the unique variance in an outcome variable explained by each predictor, it is important to enter predictor variables in a theory-sensitive manner for this kind of analysis. Both memory tasks must have involved some degree of attentional control, because the stimuli could not be recalled if they were not attended to. The executive task, however, had no clear short-term storage demands. Therefore, the executive task was entered as the first predictor, accounting for a significant proportion of variance in route learning (40%). Neither of the storage tasks contributed significant additional predictive power, suggesting that their predictive relationships with route learning, as discussed in this section, were mediated by the executive control demands of the tasks.

Despite the tacit assumptions made when using regression, it is actually very hard to establish causality. The oft-used phrase 'correlation does not equal causation' should be extended to 'neither correlation nor regression equals causation.' Using a regression model presupposes a causal relationship between the predictor and the outcome variable, but it cannot establish it. Longitudinal methods are better suited to test such hypotheses.

Matching

Matching is the equating of groups on some variable – usually chronological or mental age – to afford a meaningful comparison. It is frequently utilized in developmental disorder research, whether cross-sectional or longitudinal, with the aim of discovering whether a group with a disorder is above or below the level of task performance expected for their age or for their ability in some domain(s). The control group, then, acts a reference point for the disorder group, in order to rule out candidate explanations for any resulting group differences. Matching has become controversial, due to the fact that it ignores variability in the matching variable and is not developmental in its emphasis (see Thomas et al., 2009).

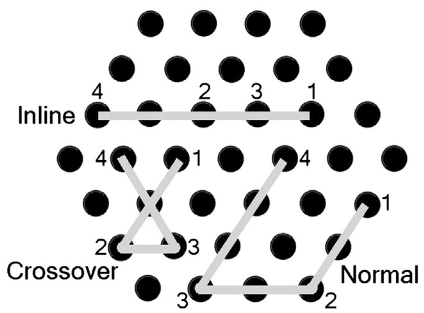

Figure 1 The task display showing examples of the paths in each condition of the experiment (the order of presentation is illustrated in the figure, but no digits were actually shown on the display; although path lengths were matched across conditions, a shorter Crossover path is shown for the sake of overall clarity).

The implicit logic behind group matching, noted by Jarrold and Brock (2004), is that matching will equate for 'noncentral' task demands: understanding instructions, controlling response behavior, selecting and using appropriate strategies, and so on. However, the mental age measures most commonly used for matching are very indirect means of achieving this: the Peabody Picture Vocabulary Test (PPVT; Dunn and Dunn, 1997) and Raven's Colored Progressive Matrices (RCPM; Raven et al., 1998) are measures of receptive vocabulary and nonverbal reasoning, respectively. Jarrold and Brock, instead, advocate control conditions that are essentially the same as the experimental task, differing only in that the target cognitive ability is not required for successful performance.

Purser (2006) investigated whether individuals with Down syndrome (DS) rely on a visual strategy to support their visuospatial short-term recall, relative to a typically developing control group. There were three conditions, presented on a honeycomb-like grid on a computer touchscreen: 'Normal' trials on which the path traced by the visuospatial sequence could be represented as a regular four-sided shape, 'Crossover' trials on which the path crossed over itself once, and 'Inline' trials on which the path fell on a single line, so that no two-dimensional shape could be represented (see **Figure 1**). The sequences were presented by circles momentarily changing color, after which the participant attempted to touch the circles in correct serial order.

Participants from DS and typically developing groups were matched on the Normal version of the task, ensuring that the two groups were matched for general factors related to successful task performance in the other two conditions. **Figure 2**a shows each group's average recall over the three conditions. The DS group was significantly poorer on the Inline version of the task than the TD group. An error analysis (**Figure 2**b) indicated that the DS group made more order errors than the TD group in both the Crossover and Inline conditions. These results indicated that the DS group found path crossing more detrimental to recall than the TD group,

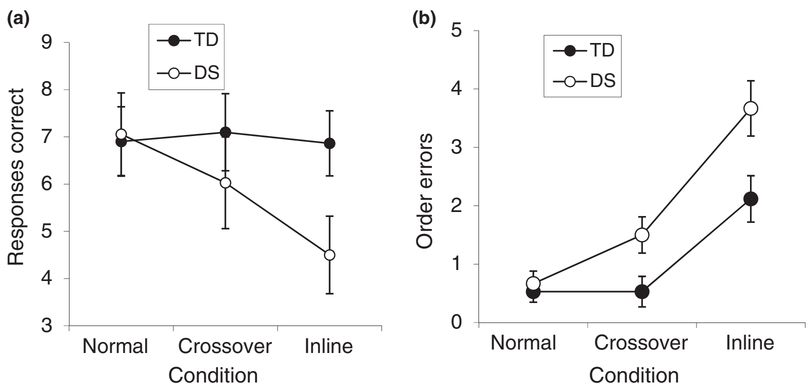

Figure 2 (a) Condition effects by group in the visuospatial recall task. Vertical lines depict standard errors of the means. Maximum score = 16. TD = typically developing; DS = Down syndrome. (b) Condition effects by group for order errors in the recall task. Vertical lines depict standard errors of the means.

consistent with relying on a visual strategy. Importantly, due to the 'task-matching' method, these differences cannot be attributed to general factors differentially affecting the groups.

Trajectory Analyses

Trajectory analyses (Thomas et al., 2009) are essentially modified forms of analysis of variance (ANOVA). Instead of comparing group means, however, the analyses involve the comparison of regression lines, or 'developmental trajectories,' between groups, across conditions, or both. Trajectories are linear functions that vary in terms of both their gradients (rates of change) and intercepts (initial levels of performance).

Trajectories are generally used to relate task performance to either chronological or mental age; they are especially useful for investigating the developmental relations that exist within developmental disorders that show uneven cognitive profiles, or *developmental dissociations*. Although longitudinal methods would ideally be used for such investigations, the cross-sectional approach can give an approximation of developmental trajectories, which can subsequently be validated by longitudinal research.

Trajectories help to answer the question 'Do individuals with a disorder perform at an age-appropriate level?' In a simple example of the trajectories approach, Purser and colleagues (Purser et al., 2011) compared word knowledge and vocabulary age in the rare genetic disorder Williams syndrome (WS), and a typically developing (TD) control group. In individuals with Williams syndrome, language development can appear a relative strength, with language level exceeding overall mental age, but the exact nature of these language abilities has been the subject of much research. In Purser et al.'s study, word knowledge was assessed with a definitions task (in which participants are asked to define words; e.g., 'What is an elephant?'). Vocabulary age was assessed via the British Picture Vocabulary Scale (BPVS; Dunn et al., 1997). **Figure 3**a shows the two groups' performance on the definitions task: the WS group's performance began at a level appropriate for vocabulary age, but then the TD group improved at a faster rate than the WS group. The gradients of the trajectories differed but not the intercepts.

Participants also completed a categorization task, which was also a measure of word knowledge but avoided some of the metacognitive demands of the definitions task, such as understanding what a definition is and how to respond appropriately. In the categorization task (**Figure 3**b), the performances of both groups developed at similar rates, but the WS group was markedly poorer than the TD group, on average, than predicted by vocabulary age. Here, the gradients did not differ, but the intercepts did.

Taken together, these results indicated that individuals with WS have poorer word knowledge than predicted by their vocabulary age, but this word knowledge improves at a similar rate with increasing vocabulary age in both WS and typical development. The 'falling behind' of the WS group on the definitions task, relative to the TD group with advancing vocabulary age, was likely due to older TD children understanding the metacognitive aspects of the definitions task better than participants with WS of a similar vocabulary age.

Brain Imaging

Although all the data we have considered thus far have related to behavioral measures, researchers are increasingly turning to brain-imaging techniques such as functional and structural magnetic resonance imaging (MRI) (see Holland et al., 2007; Knickmeyer et al., 2008, for examples of functional and structural studies, respectively) and electroencephalography (EEG) (e.g., Thatcher et al., 2008) to inform developmental theory. Such techniques allow an examination of not just how behavior and cognition change over development, but also how the brain changes, and how the relationship between the brain and behavior may alter, too. Questions being addressed include the following: what are the typical functional relationships between different brain regions over development? How do functional brain activity and the structure of the brain relate to the development of specific skills over childhood, and indeed the lifespan? What can differences in the brain tell us about why behavior is atypical

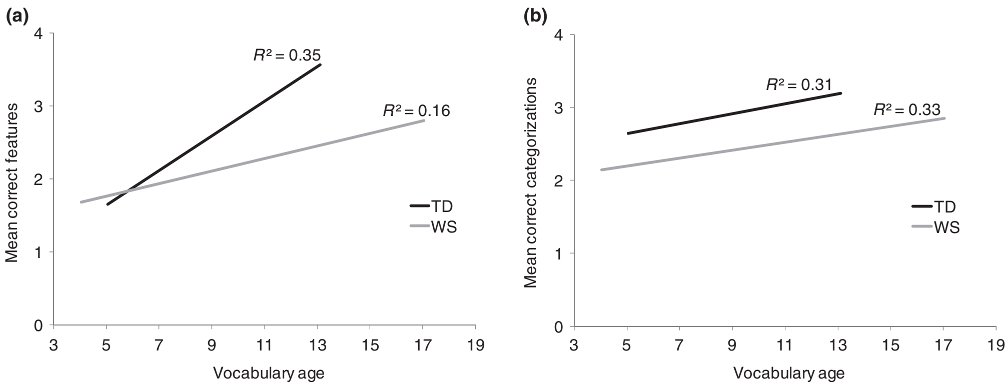

Figure 3 (a) Mean number of features given by participants in the definitions task plotted against vocabulary age in years. (b) Mean number of correct categorizations plotted against verbal mental age in years. WS = Williams syndrome; TD = typically developing. Data from Purser, H.R.M., Thomas, M.S.C., Snoxall, S., Mareschal, D., Karmiloff-Smith, A., 2011. Definitions versus categorization: assessing the development of lexicosemantic knowledge in Williams syndrome. International Journal of Language & Communication Disorders 46 (3), 361–373.

in children with developmental disorders such as dyslexia? The questions addressed using brain imaging, and the data acquired, are complex and require careful thought during the design of studies and the interpretation of results. This is especially true in the light of the many-to-many relationships between brain and behavioral measures. Individual behaviors are generated by networks of brain regions working together, and an individual brain region may be involved in generating more than one behavior. Moreover, a developmental perspective must take into account that the experienced environment may continually change over the lifespan.

While adopting brain-imaging techniques permits some key insights into the development of cognition, using these techniques with children also raises practical and theoretical issues (see Davidson et al., 2003, for a discussion of the use of functional MRI (fMRI) techniques with children). The majority of cross-sectional studies in developmental psychology require a wide age range in order to capture change over development. This presents a challenge in that the paradigm must be suitable for a range of ages, and it must be sensitive enough to measure performance at each age. Being sensitive across the age range requires that no set of participants performs at either floor or ceiling on any task. With brain imaging, this challenge is compounded by changes in physical properties such as skull thickness and brain size, as well as the propensity for young children to move about during testing. All of these factors, and many more besides, influence the quality of the imaging signal and show both individual differences and age effects. Although these issues are always relevant when working with a developmental sample, they are easier to take into account if testing the same children repeatedly, that is, if using a longitudinal design. Nevertheless, cross-sectional studies of development involving brain imaging are relatively sparse from ages 2 to 6 years, where the practical challenges of obtaining measurement are most severe.

Cross-sectional techniques can be applied to any brain-imaging study, just as they can to any behavioral study. Here we take an example of a lifespan study, emphasizing that the study of developmental processes considers trajectories beyond the end of childhood. Richardson et al. (2010) gathered receptive vocabulary and nonverbal IQ scores for 47 individuals aged between 7 and 73. These participants were then scanned using MRI to look in detail at the structure of their brains while they rested. When the relationship between brain structure and performance on the behavioral measures was analyzed, a significant correlation between vocabulary score and gray matter density was revealed in both left posterior superior temporal sulcus and the left posterior temporal–parietal junction. In the teenage participants alone, an additional correlation was discovered between vocabulary score and gray matter density in the left posterior supramarginal gyrus. When Richardson et al. examined which of these regions were activated more during auditory and visual language comprehension than control tasks, only the first two regions showed significant effects. What, then, is the function of the left posterior supramarginal gyrus, where more gray matter was observed in teenagers with higher vocabulary abilities? The authors suggested that the developmental shift in the relationship between brain structure and behavior was driven by the way in which vocabulary is learned during the teenage years; specifically, that the relationship seen in teenagers is driven by the learning style of explicit instruction through lexical or conceptual equivalents common in secondary school, as distinct from incidental vocabulary learning through interaction that is more typical in younger children and adults.

In many ways, brain imaging lends itself as well to cross-sectional designs as do behavioral measures, but it provides an extra level of understanding and complexity that offers insights different to, and arguably beyond, behavioral measures. However, the difficulties inherent to all developmental studies can be exaggerated by the demands of adopting complex imaging techniques.

Benefits and Limitations

The major benefits of cross-sectional techniques in developmental psychology are practical in nature. The first benefit is that cross-sectional work is relatively inexpensive. The usual aim of cross-sectional studies is to get a measure of change with development, which may also be achieved by repeatedly testing the same children over time rather than testing children of different ages at one point. Such longitudinal studies require repeated testing over many years, resulting in high staff and laboratory costs, a significant commitment from participants, and the risk of data loss where that commitment cannot be delivered. The second benefit relates to the difficulty of selection bias, which is common to almost all psychology experiments. Researchers often invite participants who are close by, accessible, and likely to comply with studies. In addition, people who are proactive and interested in psychology are much more likely to take up invitations or get in touch with labs. This has some serious implications for the whole field (see Jones, 2010, for a discussion of the impact of overusing certain demographics in psychology studies). A specific problem for longitudinal studies is that people drop out over time, so for some participants a researcher might have just one data point, while for others they have several. Unfortunately, who stays in the study and who drops out are often not random. Participants might drop out because they find the study challenging, or perhaps because of difficulties with travel or unemployment. This means not only that data sets are often incomplete, but also that the data that are available are particularly prone to selection bias. Cross-sectional studies avoid at least some of this difficulty.

Despite the clear benefits of adopting a cross-sectional approach when running a developmental study, there are equally a number of important limitations. Perhaps the primary limitation is that when looking for the effect of age on some cognitive measure with a cross-section of children, there is an inevitable confound of individual differences. Do these children differ on the task because one is older or as a result of some other variable, such as nonverbal IQ or attentional control, which has not been measured? This will manifest as 'error' in the statistical models used, reducing the ability to find effects of interest in the variables that have been measured. In contrast, longitudinal methods effectively control for many of these unmeasured variables, to the extent that they are stable across the time points of measurement involved in the study.

The second major challenge of cross-sectional methods is the development of an appropriate paradigm (as briefly discussed in this article). Cross-sectional methods assume that the cognitive function in question is captured in the same way across the whole range of chronological or mental ages considered. However, it is not always clear that this is, in fact, the case. There are two main situations in which the assumption may not be met. The first is when different tasks are used for participants of different ages or ability levels. Consider how one might test the language ability of an 18-month-old, a 5-year-old, and a 15-year-old. The first might rely on a parental questionnaire of the vocabulary that the child produces; the second can focus on more directly on the child's language skills in the oral domain, including both vocabulary and syntax; and the third may assess more complex aspects of, say, syntax or pragmatics in the written domain. However, the problem of using different tasks at different ages is obvious: if the task is different, then the demands must be different. This creates problems of interpretation because these differences in task demands may lead to differences in scores across the range of ages measured, rather than (or in addition to) any underlying differences in the target cognitive function.

A more basic problem is that the different tasks may be scored in different ways. For example, the RCPM (Raven et al., 1998) is a test of nonverbal reasoning for children and is scored out of 36 items. Raven's Standard Progressive Matrices (RSPM; Raven et al., 2003) is a broad equivalent for adults and is scored out of 60. How should one compare scores from each test? In this case, there is a solution, because norms are available that indicate what score the norming samples achieved on average across the whole age range, with standard deviations for each age. For a given age, participants' score can be converted into how many standard deviations they scored above or below the norm average. When such norms are not available, researchers can standardize scores against their own sample, although large numbers are generally required.

A subtler situation arises when the task used does not change but the determinants of task performance do. A clear example is the decline in working memory capacity observed in older adults. According to Baddeley's (1986) model of working memory, there is an attentional control component, the 'central executive,' and two 'slave' passive storage systems, the phonological loop and visuospatial sketchpad, which temporarily hold verbal and visuospatial representations, respectively. Older adults perform similarly to younger adults on tasks that require few executive demands (i.e., they require little attentional control), but are poorer than younger adults on tasks that do make such demands (e.g., Craik and Byrd, 1982). Thus, the poorer working memory scores of older adults reflect limitations of attentional control, but not of working memory per se.

In order to conduct valid research comparing task performance across the lifespan, researchers must analyze their main task in terms of the cognitive demands that it makes. If there is reason to believe that any of these demands, other than the target cognitive function, might change across the chronological or mental age range involved in the research, then these component demands should be independently measured so that any observed differences in the main task can be confidently attributed to the target ability rather than to the secondary demands.

A final limitation is the widespread use of linear modeling in cross-sectional studies of development. Although some cognitive changes may approximate straight lines, many may not. However, although some challenges in interpretation may arise, most linear methods, including trajectory analyses, can be adapted to nonlinear models simply by altering the model options in the statistical software used (see Thomas et al., 2009). As noted by Thomas and colleagues, the principle of parsimony may be invoked when deciding whether a linear or nonlinear model is preferable: nonlinear models involve a greater number of parameters than linear models.

Getting the most out of cross-sectional methodologies will mean taking advantage of the benefits and minimizing the impact of the limitations. Ways of minimizing the impact of the limitations might include taking care to abate potentially confounding factors where possible, and keeping response demands simple for all paradigms, while ensuring as wide a performance range as possible; using adaptive tasks is one way to achieve this.

Conclusion

The aim of this article was to describe the use of cross-sectional methodologies in developmental psychology, and to explain their origin, their strengths, and their weaknesses. We have discussed the theory behind the statistical techniques adopted in cross-sectional studies and used examples from the literature to illustrate their use.

Cross-sectional methodologies provide substantial scope for the development of highly informative studies without the cost associated with longitudinal work. The development of trajectory modeling allows a developmental perspective to be taken, at the heart of which is the aim of determining the mechanisms of change in cognitive systems. Throughout the history of developmental psychology, the establishment of statistical methods such as regression has been intimately tied up with theoretical advancements and new conceptual understanding. This is certainly apparent with respect to cross-sectional studies, although equally the statistical limitations inherent in data collection at a single point in time must be borne in mind. Development is, in its most fundamental sense, a dynamic process of change. Indeed, the word itself comes from the French *développer*, to unfold. Research into the process of cognitive development must, therefore, balance practicality with the theoretical rigor of longitudinal studies.

The future of cross-sectional methodologies lies in researchers pushing the boundaries of what questions can be asked: using trajectory analyses to trace the patterns of cognitive change, using brain-imaging techniques to answer questions about the neuroanatomical and neurophysiological underpinnings of cognition, and bearing in mind that developmental psychology is not just about cognitive development in children but also about change throughout the lifespan.

See also: Cross-Cultural Research Methods in Psychology; Equivalence and Transfer Problems in Cross-Cultural Research; Longitudinal Analyses of Sexual Development through Early Adulthood; Qualitative Methodology in Developmental Psychology.

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