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Early infant cognitive assessment: Validity of an instrument

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The present study represents a contribution to the assessment of infant cognitive development by presenting a valid instrument for observing the development of logical reasoning and executive function during the second year of life—key processes in the construction of human knowledge. The instrument constructed, called ELEDA (Early Logical and Executive Development Assessment), was a combined or mixed observation instrument composed of field formats and category systems. Its validity was calculated using generalizability theory, which enables different sources of error affecting a behavioral measurement to be analyzed jointly. The need for valid early cognitive assessment instruments such as the one in the present article is evident, since the sooner assessment is performed, the sooner action can be taken, thus optimizing the results.

Cognitive development is a process of change and successive deployment of cognitive skills starting even before birth and continuing through the entire life cycle, in close interaction with the neurological substrate and the continually changing context of each individual (Diamond, 2007b, 2009a). Many different elements interact in this continually changing process of development, and there are also many different possible forms of interaction and results (Karmiloff-Smith, 2007, 2009). Neurocognitive assessment is crucial for understanding the nature and scope of this development, subsequently enabling palliative strategies and optimizing the design of intervention strategies that respond to individual needs (Silverstein et al., 2007). Although this is relevant in any stage of development, it is even more important during the first 3 years of life, because of the numerous neuro–anatomical and functional changes that take place in interaction with the construction of important cognitive, behavioral, and social skills (Diamond, 2007a; Johnson, Grossmann, & Cohen Kadosh, 2009; Lu et al., 2009; Pastor & Sastre, 1994).

Of all these skills, the neuroconstructivist perspective of cognitive development (Mareschal et al., 2007; Quartz, 1999; Quartz & Sejnowski, 1994, 1997) highlights the importance of protologic, or logic during the first 3 years of life, because it is one of the key mechanisms in the construction of cognitive development, enabling information to be captured, elaborated, structured, and interiorized from birth, finally resulting in knowledge (Pastor & Sastre, 1994).

During the first 9 months of their lives, babies explore objects in search of information, acting with increasing degrees of intention. The basic techniques they use, such as pulling or sucking, are not applied sequentially and are undifferentiated. They are used separately and without taking into account the specific characteristics of each object. In this way, the babies gather more and more basic data on the objects they encounter. From then on, and during their second year of life, they make important leaps forward. Actions are preferentially differentiated, adapted to the specific characteristics of the objects, and coordinated. Actions become more flexible and are combined and redefined, and similar results are tested to obtain new information—all essential characteristics of what is known as "experimentation." After 1.6 years, two types of iterative actions are combined: (1) "putting together," primarily different objects (grouping) and then the same objects (collection), and (2) "distributing," in which one or various elements of a set are related with one or various elements of another set.

The combination of both types of actions, organized progressively, gives rise, after around 2.0 years, to "one-to-one correspondence" between the elements of two sets. "One-to-one correspondence" involves sequentially relating each object in a set with a different element in another set (Langer, 1986; Sinclair, Stambak, Lezine, Rayna, & Verba, 1984), resulting in a relationship of equivalence between both sets. This logical operation is particularly important, since it is a key component in the development of mathematical skills, which are essential for successfully performing in our society. For example, in counting operations, each object to be counted must be assigned a single numeral, which must also be in the proper order.

In short, the development of protologic and, more specifically, "one-to-one correspondence" is relevant for the cognitive behavior of individuals from an early age. However, despite its importance, very few studies have been published on this subject.

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In addition to logic and other basic skills, executive functions must be developed in order to progressively construct intellect; these are mostly high-level cognitive processes ("cool" executive functions), but there are also effective processes ("hot" executive functions) that allow individuals to decide when and how to use each type of stored knowledge or information (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009). Cognitive executive functions coordinate the processing of information and the control of actions to achieve previously determined objectives (Bjorklund & Harnishfeger, 1995; Heyder, Suchan, & Daum, 2004; Norman & Shallice, 1986; Zelazo, Craik, & Booth, 2004). The most important of all of the processes involved in these executive functions is "resistance to interference," which prevents an external distracting stimulus or a piece of information that is irrelevant to the task being performed from entering working memory, thus preventing execution of the task from being undermined (Dempster, 1993; Dempster & Brainerd, 1995; Dempster & Corkill, 1999; Diamond, 2009b; Houdé, 2001; Scheres et al., 2004).

Although cognitive executive functions and, therefore, the process of resistance to interference have been studied in detail in scientific literature (Friedman & Miyake, 2004; McDermott, Pérez-Edgar, & Fox, 2007; Shelton, Metzger, & Elliott, 2007; Silverstein et al., 2007; Tanabe & Osaka, 2009; Zamboni, Huey, Krueger, Nichelli, & Grafman, 2008), few studies have addressed this aspect from the perspective of development, and fewer still have addressed it from the standpoint of early infant development (Diamond, 2006; Wiebe, Espy, & Charak, 2008; Zelazo, Carlson, & Kesek, 2007; Zelazo, Müller, Frye, & Marcovitch, 2003). This situation is partly due to difficulties that are associated with the specificities of this area of research, for example:

1. Defining and measuring development is difficult. The object of study itself involves a continual, complex, diverse, multiform, and dynamic process of change that also refers to variables with multiple levels of analysis.

2. Cognitive phenomena cannot be observed directly, which makes monitoring changes even more complex. However, we can directly observe their external products: language, memory, or reasoning.

3. Cognitive processes tend to develop very quickly, making it difficult to determine the full scope of the phenomenon and giving a deceptive impression of simplicity.

4. The cognitive system is interactive; hence, all of the system components are functionally interdependent. This characteristic makes it a complex domain; therefore, for study purposes, it is normally divided into specialization plots. There are attempts within cognitive psychology to study some of the specific aspects of cognition, but it can only be fully understood by taking into account the close connection between cognition and the other components.

5. When studying cognitive development in infants, these difficulties are accompanied by others that are associated with working with very young children—for example, the instability of infant behavior, evident difficulties in verbal expression, little collaboration, and so on (Greenwood, Luze, & Carta, 2002). Consequently, the range of methodological procedures that may be used is very limited; observational methodology is one of the most appropriate—and sometimes it is the only possible—methodology (Anguera, 2001), since it enables the spontaneous behavior of individuals to be observed in their natural and habitual context.

However, these aspects—the variability and unpredictability of human behavior and the simultaneous concurrence of multiple forms of conduct and/or multiple response levels (Anguera, Blanco-Villaseñor, & Losada, 2001)—prevent the existence of standard instruments, since the natural form of the conduct studied would be lost. Consequently, observational methodology requires the development of ad hoc instruments that can be used validly and reliably to identify the studied unit of conduct. This, in turn, requires controls or filters prior to data analysis that relate to the quality of recorded data, in order to take into account possible errors or bias in these data. To summarize, observational methodology requires the performance of a control (intraobserver reliability, interobserver reliability, validity of the constructed ad hoc instrument) prior to data analysis.

This can be achieved using generalizability theory (GT), a multivariate structure developed by Cronbach, Gleser, Nanda, and Rajaratnam (1972) and adapted to observational designs by Mitchell (1979). This theory can be used to analyze all of these processes to control the quality of observed data, and even to assess the percentages of variability produced in each variable studied, either individually or in interaction (Blanco-Villaseñor, 1989, 1991, 1993, 2001; Escolano-Pérez, Blanco-Villaseñor, Anguera, & Sastre, 2007).

GT considers the existence of multiple (infinite) sources of variation (facets) in each measurement (Blanco-Villaseñor, 2001; Blanco-Villaseñor, Sastre-Riba, & Escolano-Pérez, 2010). The aim of this theory is to distinguish real variability from error variability in any measurement for subsequent comparison. It therefore requires variations in the facets (variables)—such as individuals, age, tasks, treatments, contexts, sessions, recording opportunities, and so on—and variance components analysis. These variables are the core elements of GT because they contribute information on sources of error that affect behavioral measurement. Thus, GT is a theory of the multifaceted errors of behavioral measurement (Cronbach et al., 1972).

In GT, after variance components analysis has been completed, a measurement plan must be established (Cardinet, Johnson, & Pini, 2010). This phase is used to specify the measurement objective—that is, to identify the specific admissible facets or measurement objects representing the study population, as well as the facets and measurement instruments ("observation conditions," in Cronbach terminology) representing the generalization universe. The former correspond to *differentiation*, since the real variance stems from the differences between the objects studied, and the latter correspond to *generalization* or *instrumentation*, since the measurement conditions are like the measurement instruments or means. Any facet can be attributed to either differentiation or instrumentation, according to the objective pursued.

If the observer, or observers, facet is considered an instrumentation facet, the aim is to determine whether the data obtained by an observer can be generally applied to an infinite number of intraobserver moments, or whether those obtained by 2 observers can be generally applied to an infinite number of observers. In short, the aim is to determine whether the same data would always be recorded—that is, whether the recorded data are reliable.

If the macrocategories facet and/or the category facet (actions) were considered to be instrumentation facets, this would refer to the validity of the observation instrument. An instrument would be valid when the estimated variability of the records of macrocategories and/or categories is high, resulting in a generalizability coefficient equivalent or close to 0.

On the basis of the foregoing, the present study aimed to build an instrument for observing logical and executive activity during the second year of life, calculating its validity by applying GT. The elaboration of a valid instrument for observing some cognitive behaviors during the early years of life would allow early activities to be designed and adapted to the specific needs of each child.

METHOD

Participants

Eighty children born in the Autonomous Community of La Rioja (Spain) participated in this study. The participants were studied longitudinally by administering measurements that were repeated at three ages: 18, 21, and 24 months. The treatment of participants was in accordance with international scientific research standards and ethical principles.

Instruments

The stimuli consisted of three nonverbal, closed ad hoc tasks that facilitated (1) children's logical activity, particularly the construction of "one-to-one correspondence" according to the size of the elements presented; and (2) children's executive activity, in some cases—specifically, "resistance to interference" from a distracting stimulus.

The following materials were used in each task: a set of four plastic beakers of different diameters (8.5, 7, 4.5, and 3 cm), and a set of four cork balls of the same size as the aforementioned beakers.

In the first task (Figure 1), each size of element had a color. Since the color characteristic is mainly perceived according to the size of the elements (Atkinson, Hood, Wattam-Bell, & Braddick, 1992; Ross & Dannemiller, 1999), it was considered that it would allow the participants to establish one-to-one correspondence between the beakers and the balls: All the participants had to do was to focus on the color of the element to successfully resolve the task. Therefore, this task was referred to as the "facilitating task."

In the second task (Figure 2), all of the elements were white, which meant that only information on the size of the elements could be extracted to establish the correspondence between one element and another. This task was known as a "neutral task."

In the final task, the "interfering task" (Figure 3), the color of the elements differed from their size; that is, the same-sized beaker and ball were different in color and were the same color as other different-sized elements. Since the perception of color dominated the perception of size but did not allow the participants to successfully resolve the task, color was an interfering characteristic that prevented the participants from adequately resolving the task. Size was the key characteristic for resolving the task.

A Sony DCR-TRV900E digital video camera was used to record infant activity. The data were encoded using Match Vision Studio v3.0 software (Perea, Alday, & Castellano, 2006).

The validity of the observation instrument was calculated using the GT software (Ysewijn, 1996), although it was first necessary to use the SAS 9.1.3 package Procedure VARCOMP (Schlotzhauer & Littell, 1997).

Figure 1. Facilitating task: Stimulus material.

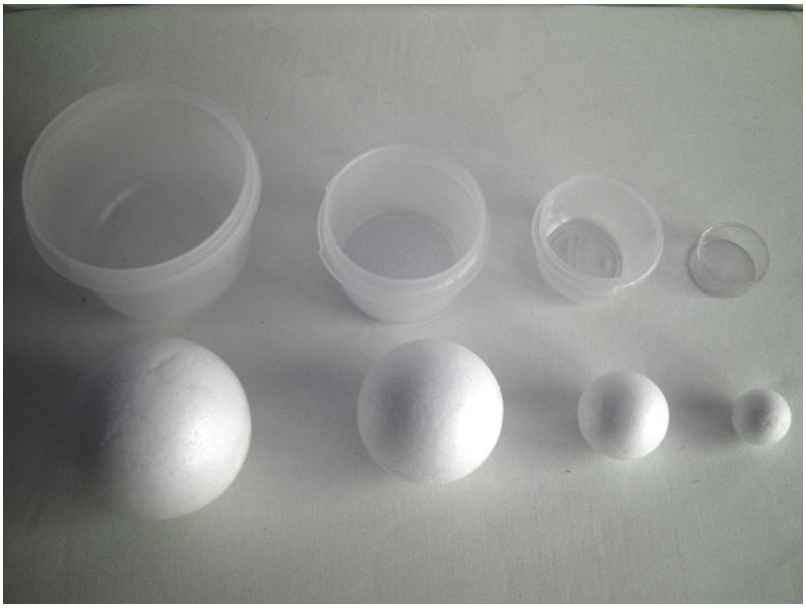

Figure 2. Neutral task: Stimulus material.

Procedure

Each participant sat on the floor opposite the material and with the same specialized adult, who was instructed not to intervene except (1) when the child requested this, (2) in a repetitive activity, or (3) when the child stopped performing the activity. The tasks were presented in the following order: facilitating task, neutral task, and interfering task. The participants had a maximum of 15 min to resolve each task.

Spontaneous infant activity was recorded using a video camera that was positioned at a distance from the child and was hardly noticeable.

Construction of the observation instrument. The taxonomic (hierarchical) system of behavioral units for observing infant logical and executive activity was developed in prior sessions through narrative recordings, characterized formally by their textual style and containing nonspecialized vocabulary based on the intentional selection of information and on a nonsequential register (Anguera, Blanco-Villaseñor, Losada, & Hernández-Mendo, 2000).

Through different semisystematization processes—the final process consisting of a list of distinctive features—these narrative recordings allowed us to identify the different actions that were developed by the children studied. These distinctive features included the following: grouping, pulling, putting a ball in a beaker, no activity, no action and not focusing on the materials, the repetition of an action without paying attention, putting a ball in a beaker and removing it quickly, fitting together, making towers, or putting two balls in the same box.

Figure 3. Interfering task: Stimulus material.

Table 1
Summary of the ELEDA Observation Instrument

Macrocategory	Category	Definition of the Category
Actor	Child	The child performing the action.
	Adult	The person monitoring child's actions.
Activity	Initial state	First action performed by the child when the session starts.
	Process	Action performed by the child between the first action in the session and the final action in that session.
	Stoppage	The child stops performing the action for at least 15 sec.
	Restart	First action performed by the child after stopping his/her activity.
	Appropriate final state	Stable result of infant action that continues when the session ends, involving the exhaustive and sequential relating of an element from one set with another from the other set according to its size.
	Inappropriate final state	When the session ends, the absence of the stable result of infant action involving the exhaustive and sequential relating of one element from one set with another from the other set according to its size.
Content	Grouping	Grouping of elements from different sets.
	Collection	Grouping of elements from the same set.
	Container-content composition of a set	Joining of two elements from the same set.
	Container-content composition of two sets	Joining of two elements from different sets.
	One-to-various/all distribution	An element from one set is sequentially related with various/all of the elements in the other set.
	Various/all-to-various/all distribution	Various or all of the elements of one set are individually and sequentially related with various or all of the elements in the other set.
	One-to-one distribution	More than one element from one set is related individually and sequentially with one different element in the other set.
	One-to-one correspondence	All of the elements in one set are individually and sequentially related with a different element in the other set, all giving rise to a lasting result.
Result	Stable result	The result of the action is tangible and lasting.
	Unstable result	The result of the action is neither tangible nor lasting.
	No result	The action does not produce any result.
Scope	Exhaustive	Participation of all of the elements in the action or in its result.
	Nonexhaustive	Participation of some elements in the action or in its result.
Adaptation	Adaptation of size	All of the interrelated elements concur with one another in size.
	Adaptation of size and color	All of the interrelated elements concur with one another in size and in color.
	Adaptation of size but not color	All of the interrelated elements concur with one another in size but not in color.
	Adaptation of color but not size	All of the interrelated elements concur with one another in color but not in size.
	Nonadaptation of size	At least one element related with another element in the other set is different in size.
	Nonadaptation of either size or color	At least one element related with another element in the other set is different in size and color.
Intervention	Physical proposal of an object	The adult shows one object or various objects to the child.
	Physical proposal of an action	The adult performs an action in front of the child.
	Verbal proposal	The adult verbally suggests performing an action.
	Maintenance of the activity	The adult physically and verbally supports the action executed by the child.
Adjustment	Adjustment	The adult's proposal is close to (1) the intended action of the child, (2) his/her current activity, and (3) his/her action skills.
	Nonadjustment	The adult's proposal is close to (1) the intended action of the child, (2) his/her current activity, or (3) his/her performance skills.
Relationship with the appropriate final state	Related	The adult's proposal contains physical and verbal elements concerning matching objects of the same size.
	Not related	The adult's proposal does not contain physical or verbal elements concerning relating objects of the same size.
Response to the adult proposal	Ignores	The child does not listen to, or ignores, the adult's proposal.
	Listens	The child accepts the adult's proposal.

On the basis of these distinctive features, an initial provisional category system was established. This was mainly adapted through the convergence between our empirical findings and the theoretical framework provided by scientific literature (Langer, 1986; Sinclair et al., 1984), but also taking into account empirical observational studies focusing on early cognition (Pastor & Sastre, 1994; Sastre & Pastor, 2001; Sastre & Verba, 2001; Vargas, Pastor, & Villares, 1998; Villares, Sastre, & Vargas, 1998). In this way, we combined (1) theoretical concepts already defined and studied in specific scientific literature on infant cognitive development, (2) categories that represent observation instruments constructed and used in other empirical studies on the construction of infant activity and executive function, and (3) empirical results providing information on other types of actions not previously defined by other authors.

The initial version of the observation instrument was gradually refined and improved in a number of pilot sessions until a definitive version was obtained.

Data analysis. Of all the sessions encoded using the final observation instrument that was constructed ad hoc (177 sessions), 16 were extracted for calculating the validity of the observation instrument developed using the GT software.

Researchers doing observational studies are obliged to show that their measuring instruments are reliable and valid—that is, that they have small errors of measurement and that the scores of individuals show stability, consistency, and dependability for the trait, characteristic, or behavior being studied. The reason for this obligation is practical: If the measure is not reliable, it cannot be expected to show lawful relationships with other variables being studied (Mitchell, 1979).

Similarly, the predictive usefulness of observational measures (validity) is limited by the stability and consistency of the scores obtained from the observational instruments.

The validity of the instrument was calculated using 16 observation sessions at three ages (18, 21, and 24 months) and in the three tasks (facilitating, neutral, and interfering). They were extracted randomly on the basis of these criteria (presence of all levels of the variables studied). The number of sessions used (16) was determined by the achievement of a high degree of validity.

The validity of the instrument was calculated using generalizability coefficients (using the GT software) of a single measurement plan with three facets—observer, macrocategories, and categories—in which the observer facet was always the differentiation facet and the macrocategories and categories facets were the instrumentation or generalization facets.

Beforehand, the variance components were calculated.

RESULTS

Observation Instrument

The definitive observation instrument that was constructed ad hoc for encoding the development of logic and executive function in the infants was called ELEDA (Early Logical and Executive Development Assessment), and it was a mixed or combined system of field formats, with category systems nested exhaustively and mutually exclusively in each macrocategory in the field formats.

Thus, the system contained 10 basic macrocategories representing the dimensions or axes of the study in accordance with the objectives of the present research, and which tended to coexist. The different category systems comprising each of these were formed, in turn, by a variable number of types of behavior or categories, ranging between a minimum of 2 and a maximum of 8. In total, 37 types of behavior were nested in the 10 macrocategories.

Each macrocategory and category in this observation instrument contributed relevant information for the study of the development of logic and executive function in the infants, since they responded to the specific objectives of the study. The original and full version of the observation instrument contained the definitions, codes, examples, and counterexamples of each macrocategory and category in the instrument, always in text and visual format to facilitate their understanding and subsequent application.

Table 1 presents a summary of this instrument.

As can be seen, the instrument combined various taxonomic levels of behavior, making this a multidimensional study.

Control of Data Quality: Validity of the Observation Instrument

The results for the validity of the observation instrument that was created ad hoc are shown in Table 2.

The 16 sessions represented maximum variability (around 96%) when the macrocategories and categories facets were considered jointly, the residual value always being null variability (observer(s) × macrocategories × categories = 0). The maximum variability of both the macrocategories and the categories in all 16 design structures (ranging between 93% and 99%) allowed us to identify precisely what had been encoded or valued in one category or another.

Significantly, in addition to the high variability in the macrocategories, which was even higher in the categories, the generalizability coefficient value obtained was close to 0 in all of the sessions. This suggests that what had been encoded in each macrocategory or category was different; that is, each macrocategory or category referred to different questions and could therefore not be generally applied to other possible macrocategories or categories. In short, it was concluded that the validity of the instrument was excellent.

Table 2
Summary of the Validity Calculation Results

Session % Variability	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Macrocategories	61	47	46	37	46	39	28	52	29	33	61	65	78	77	47	46
Observer × Macrocategories	1	1	0	1	1	1	1	0	2	1	3	2	1	3	0	1
Categories	38	51	53	59	49	60	68	45	66	63	36	28	19	16	52	52
Observer × Categories	0	2	0	3	3	0	3	3	3	3	1	5	2	4	1	1
Macrocategories × Categories	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Observer × Macrocategories × Categories	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Generalizability Coefficient	≈0	≈0	≈0	≈0	≈0	≈0	≈0	≈0	≈0	≈0	≈0	≈0	≈0	≈0	≈0	≈0

DISCUSSION

The validity of the constructed instrument, calculated by GT, was excellent. The analysis of the 16 observation sessions by GT provided a single three-faceted design structure (observers, macrocategories, and categories, individually or in interaction) for analyzing the reliability of the same using filters, which are essential for obtaining high quality data (validity).

Thus, the validity of the instrument designed (ELEDA) was assessed using a new variance analysis method that represents an improvement on previous calculation methods, which failed to cover all of the potential sources of variation, not only from individual intra- and interobserver differences, but also from different sessions, from time elapsing between one observation and another, and so on. Therefore, this method allows for estimated variance to be attributed to each source of variation or for these sources of variation to be considered simultaneously. In psychological assessment, we therefore require a multivariate theory that takes into account all possible sources of error since, according to the American Psychological Association (APA), the success of interventions depends on the reliability and validity of the data gathered during the assessment process (APA, 2005).

The present study also involved the construction of a valid observation instrument for observing and assessing some cognitive behavior in children: ELEDA.

This instrument can be adapted to the requirements of computerized recording and encoding programs that are different from the one used here—for example, the Observer XT 9.0 software (Noldus Information Technology, 2009), CODEX (Hernández-Mendo, Anguera, & Bermúdez Rivera, 2000), and so on—as well as other standard technological tools, such as handheld computers, which are an economical and versatile alternative to observational recording (Sarkar et al., 2006), without undermining the validity of the instrument in any way. This flexibility strengthens the use of this instrument and consequently means that certain benefits of computerized assessment, already acknowledged by the APA in 1986, are available to a larger population.

In short, the present research contributes findings that will help us to obtain a better understanding and knowledge of some aspects of human cognitive behavior and its variability.

The importance of early assessment at the time of development means that we are not only able to act at an early stage, but also to apply preventive and optimization measures in order to obtain lasting benefits, since what occurs in early infancy has a lasting effect on cognitive capacity, personality, and social behavior (McCormick et al., 2006; Picciolini, Giannì, Vegni, Fumagalli, & Mosca, 2006; Poch et al., 2003; Sonnander, 2000; Stanton-Chapman, Chapman, Bainbridge, & Scott, 2002).

The foregoing reveals the need for interdisciplinary collaboration among general and child health care, education, and social services professionals to construct valid assessment instruments for gathering data, as well as for the subsequent design and application of prevention and intervention programs that are more adapted to the needs of each child and family, from the first stages of life or even earlier. The subsequent importance of such action at personal, family, psycho–educational, and social levels is undeniable.

To summarize, there is a clear need for valid early cognitive assessment instruments, since earlier assessment allows actions to be taken sooner and better results to be obtained. The present study has aimed to contribute to this objective.

AUTHOR NOTE

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