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978-0-521-38275-5 - Human Cognitive Abilities: A Survey of Factor-Analytic Studies

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Excerpt

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PART I

Introduction to the Survey

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1 *The Study of Cognitive Abilities*

*Our work is primarily with the
grade book of the psychologist.*
Clark Wissler (1901)

SOME PROBLEMS OF DEFINITION

A predominant and recurring concern throughout this book is the identification and description of cognitive abilities. I had better be clear, at the outset, on what I mean by *ability*, *cognitive ability*, and related terms.

Ability

Although the term *ability* is in common usage both in everyday talk and in scientific discussions among psychologists, educators, and other specialists, its precise definition is seldom explicated or even considered. It is a word that seems to be accepted as a sort of conceptual primitive, and in fact it is intimately related to such commonly used words as *able* and the simple modal auxiliary *can*. It is sometimes used to characterize material objects, as in the sentence “This bullet has the ability to penetrate a wooden board three inches thick.” More frequently, however, it is used to characterize attributes of human individuals, as in expressions like *athletic ability*, *musical ability*, and (in the context of this book) *cognitive ability*. It expresses a kind of *potential*, a term which has merited the attention of philosophers of education (Scheffler, 1985).

Oddly enough, dictionaries are of little help in developing an exact, analyzed meaning of the term. The *American Heritage Dictionary*, for example, defines ability as “the quality of being able to do something; physical, mental, financial, or legal power to perform.” In the present context, of course, we can lay aside concern with financial and legal powers, but mental powers, and possibly physical powers, remain of interest. Dictionary definitions often have an air of circularity, as is the case here: *ability* is defined in terms of “being able to perform something” but *able* is defined as meaning “having sufficient ability.” Dictionaries of psychology might be more useful, but it happens that the word *ability* does not appear either as an entry term or in the index of a recently issued *Encyclopedic Dictionary of Psychology* (Harré & Lamb, 1983), although it is used there in

numerous contexts, for example, in defining intelligence as “the all-round mental ability (or thinking skills) either of human or of lower animal species” (p. 313). In older dictionaries of psychology, considerable attention is devoted to defining ability and related terms. English and English (1958), for example, define ability as “actual power to perform an act, physical or mental, whether or not attained by training and education.” They continue:

GENERAL ABILITY is concerned with all sorts of tasks, but especially those of a cognitive or intellectual sort. *Syn. intelligence*. SPECIAL ABILITY has to do with a defined kind of task. Each special ability should, when possible, be so defined as not to overlap with other special abilities.

Curiously, none of these definitions contains, in any explicit way, the notion that there can be variations in ability over individuals.

It seems, therefore, that we must pursue a bit of logical and semantic analysis to arrive at a more precise definition of the term *ability* as it is to be used in this book. Some issues to be addressed are: In what sense does ability imply “potential”? Is ability a matter of degree, and if so, to what extent can its degree be quantified? To what extent may ability vary within an individual and across different individuals? How general is ability, that is, does it apply only to single performances, to some class or classes of performances, or to all possible performances? To what extent is an ability to be construed as a “trait” of an individual? Let us first consider these questions in the case of the physical ability of strength, because this case affords a concrete, easily grasped context in which to do so – a context more easily handled than if we were to consider a mental ability of some kind.

Every ability is defined in terms of some kind of performance, or potential for performance. Physical strength would have to be defined in terms of a performance that would require physical strength. Lifting 100 pounds of weight on a barbell would be one such performance. Suppose that an individual is characterized as possessing the ability to lift a barbell with 100 pounds of weight on its ends. This implies that the individual has the *potential* of doing so *if conditions are favorable to it* – that is, if a 100-pound barbell is available, if the individual is fully conscious and attentive, is willing and motivated to do so if asked, and can assume an appropriate position and a good grip on the barbell to perform the task. Nevertheless, even the concept of potential has to be thought of in probabilistic terms. If the individual were tested for lifting a 100-pound barbell on 100 different occasions, he or she might succeed, say, on only 95 of these; various unforeseen or unknown conditions might prevent the person from performing on the other five trials. Still, we would be inclined to admit, on this basis, that the individual *does* have the ability to lift a 100-pound barbell. In fact, if the individual succeeded on only *one* occasion, we might still be inclined to ascribe that ability to the individual. Note that holders of world records in athletics often attain their records on only one or a very few out of many trials;

yet, we are willing to grant these people ability to attain the world record even if success is attained only occasionally. In such cases ability is defined in terms of maximal performance. As we shall see, however, this is not the way in which ability is best defined in psychometric terms.

Thus far we have considered physical strength only in terms of a single, narrowly defined task – lifting a 100-pound barbell. But this would hardly be a particularly difficult task for many individuals, although it might be difficult for many others (say, young children). Therefore, ability or lack of ability to lift a 100-pound barbell might tell us little about an individual's physical strength. If we want to ask "how strong is this individual?" a more informative procedure would be to give the individual trials with barbells of different weights, using both light ones and heavier ones. This means that physical strength ability would now be defined in terms of a *class* of highly similar tasks, less narrowly defined than before, but still restricted to the barbell-lifting task. The measure of physical strength would come out of finding at what weight, in this series or class of tasks, the individual would start to have difficulty, in the sense of having a less than 100% probability of being able to lift that weight. (We might have to control for fatigue effects, by randomizing the trials with respect to the weights used, but for now let us ignore this problem.) There are considerations, from the technical discipline known as psychophysics, whereby it turns out that the most accurate or reliable measure of individual differences in strength would be at that weight where the individual has just a 50% probability of being able to lift the weight, for example, 225 pounds for a certain individual. From a series of trials with different weights, it would be possible, at least in principle, to estimate the point on the weight scale where an individual's probability of success would be 50%, and this would be the most reliable *quantified* measure of barbell-lifting ability, even though it does not indicate the *maximal* weight the individual might be able to lift.

With this procedure, it would be possible to compare different individuals for barbell-lifting ability, and to form a statistical distribution of the measurements for different samples of individuals – individuals of different ages, genders, states of health, etc. The measurements, incidentally, would be given in absolute terms, that is, on what Stevens (1951) called a *ratio scale*; it would be reasonable, for example, to call an individual who has a 50% chance of being able to lift a 400-pound barbell twice as strong as one who has a 50% chance of being able to lift a 200-pound barbell.

It would be of interest, also, to plot curves of individuals' probabilities of successful weight-lifting performance as a function of the weights. A sample series of such curves for a few individuals might look something like those in Figure 1.1. I call such curves *person characteristic functions* (PCFs; see Carroll, 1990). The 50% points on these curves, referred to the baseline, are the measurements of weight-lifting ability; these may be called *liminal* or threshold levels. Thus, Curve A is for a comparatively weak individual, who has a 50% chance of lifting a

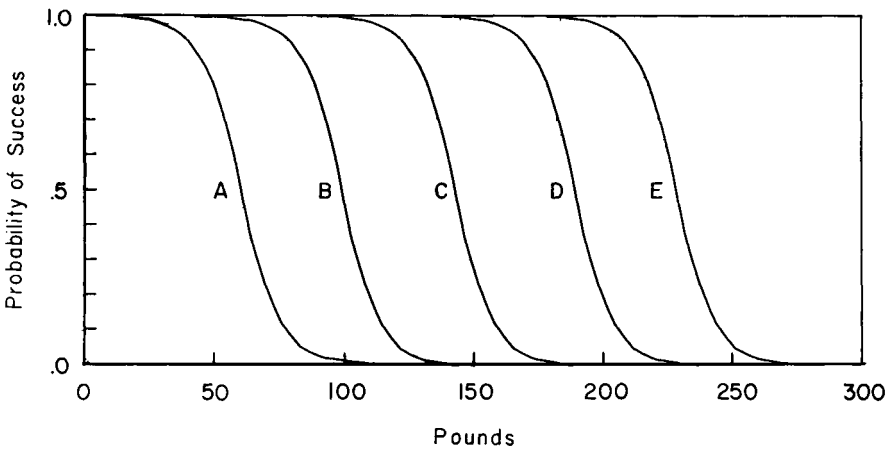


Figure 1.1. Illustrative Person Characteristic Function (PCF) curves for a barbell lifting task (hypothetical).

62-pound barbell and whose liminal level of weight-lifting ability is therefore 62 pounds. Curve E is for a comparatively strong individual – at least if we consider strength or weakness with respect to performance on the barbell-lifting task. This individual has a 50% chance of lifting a 228-pound barbell. The slopes of these curves are shown as fairly steep only because I assume they would have that degree of steepness; exactly how steep they could be is determined only by empirical investigation. In any case, the steepness of the curves would be associated with accuracy of measurement. If the curves were much flatter, this would imply that individuals' performances would be much more variable from trial to trial, even, possibly, that our barbell test of strength is for some reason not a good or appropriate one. Regardless of the steepness of the curves, they are in principle *monotonic descending*; that is, they always descend and never rise. It is unreasonable to expect that an individual who has a low probability of being able to lift a relatively light weight would nevertheless have a higher probability of being able to lift a heavier one.

The question now arises: How general is physical strength ability? It could be objected that barbell-lifting might be only a very specific skill. Common observation suggests, however, that a person who is very strong in the barbell-lifting task would also be strong in other physical strength performances, such as push-ups or pull-ups. This hypothesis could be examined by testing a group of people not only on the barbell task but also on a series of these other tasks. The group would have to exhibit some variability of performance on the barbell task; that is, it would have to include people whose abilities range from weak to strong on this task. The generality of physical strength ability would be judged from the correlations among the various tasks, that is, from the degree to which

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the individuals' measurements on the different tasks correspond to each other, or show similar rankings. If the correlations were all high – particularly if they were about as high as they could be in view of the reliabilities¹ of the measurements – we would conclude that physical strength ability is an ability that generalizes perfectly over the series of physical strength tasks that were employed. If the correlations were not significantly different from zero, despite high reliabilities of the measures, we would conclude that each task measures a different ability. If the correlations were significantly positive, but still somewhat lower than the maximal values they could attain in view of their reliabilities, we would probably conclude that there is a general physical strength ability measured to some extent by each task, but that each task measures, in addition, some rather restricted special ability. That is, we might infer that doing well in each task requires, in addition to a general physical strength ability, some special skill.

I am not aware that any thoroughgoing investigation of physical strength abilities like these is available (but see Fleishman, 1964). My guess is that the most likely outcome would be the last one mentioned in the preceding paragraph. Namely, there is a general physical strength ability measurable in a wide variety of physical tasks, but some tasks would require abilities more or less unique to themselves, possibly reflecting strengths or weaknesses in particular groups of muscles used in the tasks, or special strategies in performing particular tasks.

Still other questions would arise. How fixed is the ability? Does it vary over time? In the case of physical strength ability, common observation would suggest that over some short period of time – say a day or a week, or even longer – physical strength ability would not vary much at all, unless an individual takes special steps (like doing exercises) to improve his ability, or becomes subject to some debilitating conditions. Degree of physical strength ability can thus be regarded as a characteristic or trait of the individual, measurable at any particular point of time. It might vary somewhat more if measured at long intervals – in each of a number of years, say, in a mature adult. If considered developmentally – that is, if measured at each of a series of ages in a child – it would tend to increase, but the ranking of a number of children on this ability might tend to stay relatively the same, in which case we might infer that some developmental parameter of physical strength ability would be characteristic of each child. Such a developmental parameter could be calculated either on the basis of a series of measurements over a number of years, or possibly on the basis of noting a child's standing relative to those of a population of children of comparable age, physical size, or other attributes. In any case, such a developmental parameter would be a secondary, derived type of measurement, to be clearly labeled as such.

We have assumed here that an ability can be regarded as a *trait* to the extent that it exhibits some degree of stability or permanence even over relatively long periods of time. Many abilities do show this kind of stability. If an ability is found

to be highly variable over time, a particular measurement of it would be best regarded as reflecting a *state* rather than a *trait*, just as a measure of a person's temperature might indicate presence of a fever.²

We are now in a position to define *ability* in a more precise way than before:

As used to describe an attribute of individuals, ability refers to the possible variations over individuals in the liminal levels of task difficulty (or in derived measurements based on such liminal levels) at which, on any given occasion in which all conditions appear favorable, individuals perform successfully on a defined class of tasks.

In this definition, levels are specified as *liminal* (threshold) values in order to take advantage of the fact that the most accurate measurements are obtained at those levels.

Something needs to be said about the concepts of “task” and “defined class of tasks.” Dictionary definitions of the word *task* do not adequately convey the characteristics and structure of what is intended here, and some connotations of the word (its association with the notion of work, the assignment of tasks by superiors, and the difficulty, tediousness, and/or aversiveness of tasks) are irrelevant. We may define a *task* as *any activity in which a person engages, given an appropriate setting, in order to achieve a specifiable class of objectives, final results, or terminal states of affairs*. It is to be understood, however, that “finality” is only relative; the end result or terminal state may only lead to another task, either a repetition of the same task or a different one. The specifiability of the end result of a particular task is crucial, however, because the individual performing the task must have some notion of what type of end result is to be attained and possibly of the criterion or criteria by which attainment of the end result is to be assessed. Many tasks are imposed by others, as when an individual is asked a question, presented with an item on a psychological test, or requested to perform some action. Many other tasks, however, are self-imposed, as when an individual decides to write a letter, sing a song, memorize a poem, or seek some action on the part of another person or a group. It can be the case that some kind of ability, and its level, could be inferred from an individual's successful or unsuccessful performance on any of such tasks, whether self-imposed or imposed by another.

By a *class of tasks*, we mean a group or series of possible tasks that have at least some identical or similar attributes. These attributes may refer to the kinds of stimuli that must be dealt with, the kinds of actions that must be performed, or the means by which those actions can be performed. The greater the similarities, it may be assumed, the more likely it is that the same or similar abilities of performance are involved. In the illustration used above, a highly similar group of tasks was that represented in the series of tasks utilizing barbells of different weights; the only difference among the tasks, ideally, would be the weights used. A less similar group of tasks was that represented by the barbell task, the push-up task, and the pull-up task, taken together; their similarity

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consists mainly in the fact that they require some kind of muscular strength to achieve the desired end results.

It may be assumed that tasks vary in *difficulty*, that is, in the probabilities that individuals will be able to perform them. When the tasks vary in only one parameter, like the series of tasks involving weights on a barbell, it is possible to determine a liminal probability by giving trials with different values of the parameter. When the tasks differ in their parameters, but still can be found to tap the same ability, a measure of an individual's ability could be obtained only by somehow aggregating the measurements on a series of tasks. For example, if general physical strength were to be measured with three tasks – a barbell task, a push-up task, and a pull-up task, – the final measurement could be obtained from some function (for example, a weighted sum) of the scores on these three tasks.

It is on the basis of these concepts that we can begin to see how various human abilities may be defined and measured. In common parlance we may speak, for example, of musical ability, athletic ability, and learning ability. In each case, it is presupposed that a particular class of tasks is involved. Nevertheless, it would be recognized that some abilities could be more narrowly defined, with a corresponding restriction of the class of tasks to which they apply. For example, although there might be a rather general musical ability exhibited by relatively good performance in a wide variety of musical activities – singing, performing on one or more musical instruments, reading music at sight, composing music, etc. – one might recognize special abilities in each of these activities; that is, there is a special class of tasks called “singing,” a special class of tasks called “playing classical music on the piano,” and so forth, so that “singing ability” and “classical piano-playing ability” could be defined as somewhat separate abilities. Similarly, it is commonly recognized that there are different types of athletic abilities – in distance running, playing football, playing basketball, etc. – and that these abilities are only loosely related. People who are good distance runners are not necessarily good basketball players, and vice versa.

As we shall see, the investigations dealt with in this book can be regarded as attempts to identify abilities by systematically classifying different tasks with respect to the abilities they appear to require.

Cognitive Ability

Since this book is concerned with a class of tasks designated as *cognitive*, I must specify what I refer to by this word as used in the expression “cognitive ability.”

Insofar as we have defined *task* as any activity that a person may engage in (or be made to engage in) in order to achieve a specifiable class of terminal states of affairs, and insofar as it may be assumed that the person must have a notion of what is to be performed, one might conclude that *any* task is automatically a *cognitive* task – even the task of lifting a barbell, or of digging a hole in the

ground. By using the adjective *cognitive*, however, I mean to limit the range of cognitive tasks to those that centrally involve mental functions not only in the understanding of the intended end results but also in the performance of the task, most particularly in the *processing of mental information*. That is, a cognitive task is one in which suitable processing of mental information is the major determinant of whether the task is successfully performed. Although barbell lifting may involve certain kinds of processing of mental information (kinesthetic perceptions of the barbell's balance and one's grip on it, for example), successful performance of the task is determined mainly by the physical strength of the muscles involved, and thus we would not call it a cognitive task. In contrast, the task of repeating a series of digits (as in a memory-span test) is a cognitive task because it requires storing the digits and their order in short-term memory, and retrieving them, in addition to chunking or otherwise manipulating the materials to be repeated. I define a cognitive task, therefore, as *any task in which correct or appropriate processing of mental information is critical to successful performance*. A cognitive ability is *any ability that concerns some class of cognitive tasks, so defined*. At many points in this book we will be concerned with what kinds of mental information have to be processed or operated on in the classes of tasks associated with particular cognitive abilities. Here it is necessary to consider what *cognitive processes* are, and what kinds of processes are involved in mental information processing.

Cognitive Process

In general, a *process* refers to any action or series of actions by means of which something is operated on to produce some result. A *cognitive process* is therefore one in which mental contents are operated on to produce some response. These mental contents may be representations or encodings either of external stimuli or of images, knowledges, rules, and similar materials from short-term or long-term memory. The response may be either covert (generally unobservable) or overt (observable). In the context of mental testing, only observable responses are admissible as data, although it may be useful, to explain such data, to develop hypothetical constructs concerning covert responses.

Many cognitive tasks are complex, but can often be analyzed into distinct processes, stages, or components. Sternberg (1977), for example, has provided one possible way in which to analyze typical analogies tasks found on many intelligence and scholastic aptitude tests. He proposes (pp. 135–137) that such tasks (like evaluating the correctness of the verbal analogy *red:stop::green:go*, symbolized as *A:B::C:D*) can be analyzed into the following components:

Encoding: The process of translating each stimulus into an internal representation upon which further mental operations can be performed.

Inference: The process of discovering a rule, *X*, that relates the *A* term of the analogy to the *B* term, and storing the rule in working memory.