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RESEARCH ARTICLE

The Ergodic Moment as a Way to Enable the Individual Measurement in Clinics

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ABSTRACT:

Is the measurement in clinics of tests based on performance, when only one measurement is taken, a correct way to indicate the true measure of that individual's ability? In this theoretical article we show that this is a wrong way. We first recall Molenaar's approach when he invokes the ergodic theorems to show that only in ergodic populations it is possible to transpose the population parameters to measure the individuals. Since the individual processes which develops in time are non-ergodic by their own nature, the first author developed the concept of Ergodic Moment and we show that in tests based on performance, a vocabulary test in our example, we may create an ergodic population, which allows us to transpose the population ability to measure the ability of the individual.

Keywords: transposition of population parameters; individual measurement; ergodic moment.

The Problem

There is one main difference between areas of knowledge which focus in the population as their field of study and areas that focus on the individual and his issues, their focus says everything. The sociologists draw the samples from a population and use them to estimate parameters of that population. On the other hand, the psychologists working in clinics have been doing almost the same thing i.e. drawing the samples from the population and use them to estimate parameters of the individual[1]. But should they?

In our point of view the answer is no. As we explain below this standard practice is wrong, since what they are estimating is just random points, only measurements which do not reflect the individual being estimated. This should be corrected as we propose in this paper. The tests applied to the individual should be repeated at least ten times, a reasonable amount, which do not undermine the usual clinical practice.

A Review of the Practice

In the context of the clinic, building inferences about the individual is a basic assumption and the application of tests has been used for this. They have been applied in the same way for about a century in all areas of the clinic, be it Psychology, Medicine or Occupational Therapy[2]. The clinician asks the patient to answer the items of a test. For example, suppose a clinical psychologist assumes that his patient is suffering from depression, and then applies a test that measures depression. This is administered once, and the clinician calculates the patient's score on the test. Then the clinician compares the patient's score to the standards of the test scores, estimated via the application of this test in the population of which the patient is a member, in order to infer whether the individual is depressed and to what degree. By comparing the patient's scores with the test's population scores, the clinician infers whether the patient has any degree of depression the test is supposed to measure[1]. This is very simplified example and does not represent the complexity of clinical practice. However, this example is enlightening in that it shows that the usual way clinicians generate evidence about the individual through test-taking is usually by testing the individual once and comparing the scores obtained with the scores of the population to which the individual belongs. This is what we call a direct transposition of population estimates to generate information about the individual[3].

The Problem Revisited

Peter C. Molenaar has published several articles that question the entire scientific practice of building inferences about the individual from population estimates. He warns about the ergodic theorems in the theory of stochastic processes, elaborated in the 1930s[4], and explains that they have direct implications to psychological studies that make a direct transposition of population estimates to generate information about the individual. Molenaar explains that this can only be done if the processes which generates information about the individual are ergodic. An ergodic process, in essence, must be stationary and homogeneous[5–7]. For instance, the ergodic theorems demonstrate that the occurrences of a system only exhibit the same behavior if they are ergodic. We may consider a population as a system, and the occurrences of the system the members of the population. The occurrences constitute the stochastic process[2].

In this way, we can say that the ergodic theorems require that all members of the population must present a similar behavior or possess a similar structure to be considered ergodic. The behavior of individuals must be homogeneous, if they show the same characteristics and stationarity, if the homogeneous nature does not change over time[7].

Let us assume that a population possesses ergodic characteristics, therefore if a test is valid for the population, then it is also valid for each individual that is a member of the population. In addition, the population estimates of this test may be directly applied to generate inferences for each individual of the population. Conversely, in non-ergodic populations, the population estimates must not be transposed to generate direct inferences about the individuals of these populations[7].

Molenaar[5] argues that ergodicity has implications for the entire scope of quantitative methodology in Psychology, which inevitably extends to encompass the construction of tests and their validation. He also warns that many areas of Psychology deal with phenomena and populations that are non-ergodic and make this direct transposition in a mistaken manner. In other words, if individuals from a certain population take a test, the responses of each individual constitute a process and ergodicity means that the variation between individuals and the variation in a single participant's time series, i.e. the variation over time for a single individual, must be the same[1].

Furthermore, Gomes et al[1] discussed Molenaar's problem in the context of testing in clinical practice and its feasibility. In non-ergodic phenomena the current clinical practice of testing the individual is an equivocation, i.e., applying a test only once on the individual and comparing that score to the estimates of that test in the population for generating inferences about the individual. That would be a direct transposition. Without the possibility of transposition, the clinician would need to perform the validity analysis of the test on the individual himself. Under normal conditions this would be impossible. For example, for a factor analysis of items to be done, usually at least 100 cases are required, and this in very simple factorial structures where the test has few items and few latent variables involved. At the individual level, this would require applying the test at least 100 times on the same individual, making testing in the clinic impossible.

Several proposals for estimating an individual's factor structure adequately have been developed. The earliest one was the p-technique, proposed by Cattel[8], used to analyze the factor structure of the individual from several measurements of the same individual[9–13]. This technique has been criticized for not considering the time dependence between measurements of the same individual. In order to overcome this limitation, different dynamic factor analysis models have been put forward. For example, the process factor analysis model[14], the white-noise factor score model[15,16], the dynamic factor model using the Kalman filter and the dynamic structural equation modeling[13]. These techniques have been used in empirical studies[17–19]. In addition to these propositions, the group iterative multiple model estimation[20], the general latent modeling approach[21], the time series factor analysis[22], the nonequivalence estimation method[23], the idiographic filter[24], the integrated state-trait model[13], and the Latent Markov Factor Analysis[25]. Nevertheless, these techniques have an important limitation: they demand a large amount of measurements of the same individual, making the production of the individual's estimate in the clinical context not feasible.

To date, we are aware of one proposal that has attempted to deal directly with this problem of the feasibility of testing the individual in clinics. Jelihovschi and Gomes[26] attempted to create a simulator that generated simulated results of the individual's responses from 3 or 6 applications of a test on that individual. The goal of this simulator, called simerg, was that the clinician would only need to apply a test up to a maximum of 6 times on the individual and the simulator would be able to simulate a trajectory of responses from that individual in order to generate simulated responses as if the individual had responded 90, 100, or more times. This is an interesting proposal, but it is still in its very early stages.

The Ergodic Moment

Another proposal that has the potential to be promising is the purpose of this article. The idea comes from the definition of an ergodic process, i.e. from the fact that a constant outcome process is ergodic by definition, and also that a psychological test has a chance to become constant after only 10 repetitions. It is as if the process started at that point where it becomes constant and repeats itself as long as possible. It is stationary and homogeneous because it never changes, and therefore all of its parameters can be compared to those of the population. The point where the process becomes constant is called "Ergodic Moment" (EM).

By using the concept of ergodic moment many clinical testing situations become feasible since 10 repetitions of a test can be done in one to a few days. In this case, the important thing is to generate a test that allows the individual's performance to reach its maximum and become constant, so that at this instant it becomes homogeneous and stationary. This moment is what we define as EM. If all individuals in any population have this ergodic moment, then the population itself is ergodic and its parameters can be transposed to any individual.

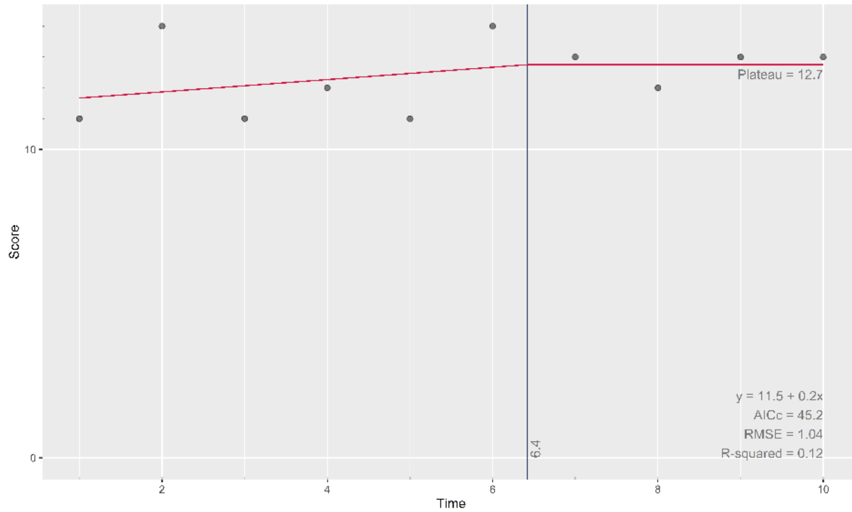
An Example

We will show this idea by means of an example. Our example involves applying a BAFACALO vocabulary test to a group of college students from a Brazilian state university (Table 2). In this example, we applied the vocabulary test 10 times to each student. The student took the test within 5 minutes, rested for about 3 minutes, and took the test again, until they completed the 10 occasions of measurement. The test was administered to 24 students, making a total of 240 cases.

By no means should the population be composed of students taking the test only once, because those results may be understood as the first point of a process which is not ergodic, therefore, the population is also not ergodic.

For each student, we estimated his EM, using the linear plateau growth function. This function proved to be appropriate to estimate the EM for all students. For most of them, the coefficient of determination (R^2) of the growth function was very good, being greater than 40% (see the fourth row in Table 2). In some cases, there was a low R^2 due to the high variation of the student's scores, but the asymptote line of the growth graph in these cases shows that the estimated asymptote was appropriate. Figure 1 shows an example where this occurred. Note that the R^2 is equal to 12%, but the asymptote line, shown in red, is appropriate to represent the point at which the scores became ergodic.

Figure 1. Example of a student's ergodic moment estimate where the R^2 is low, but the asymptote line indicates that the estimate is appropriate to indicate the ergodic moment.



The individual reaches the breakpoint of 6.4 and the score of 12.7 points indicates his EM (Figure 1). The students' performance on a given testing occasion is always an integer. Therefore, whenever the EM has a decimal of .5 to .9, that value is rounded to the numeral above, provided the individual has a performance that presents that value. If not, the closest value is chosen. In the case of this student, his score of 13 points is the one selected to characterize his ergodic performance.

After defining the ergodic performance of each individual (Table 2), we created a data frame in which each row represents the EM of each student and each column represents their score on each item of the test. This data frame is composed of 0s and 1s, where 0 represents a wrong answer and 1 a right answer on the item. Since this data frame represents only ergodic performances, it forms an ergodic population. In this population it is correct to estimate its parameters and use them in a direct transpose to build inferences about each individual.

Using the constructed data frame, we applied the Rasch model and estimated the item (beta) and person (theta) parameters on the vocabulary latent variable (Figure 2 and Table 2). The percentiles of people's vocabulary ability (thetas) were calculated (Table 1) and then we compared an individual's ability to the population, making inferences about the level of this individual's ability by taking the population's thetas as a reference.

Figure 2. Distribution of thetas

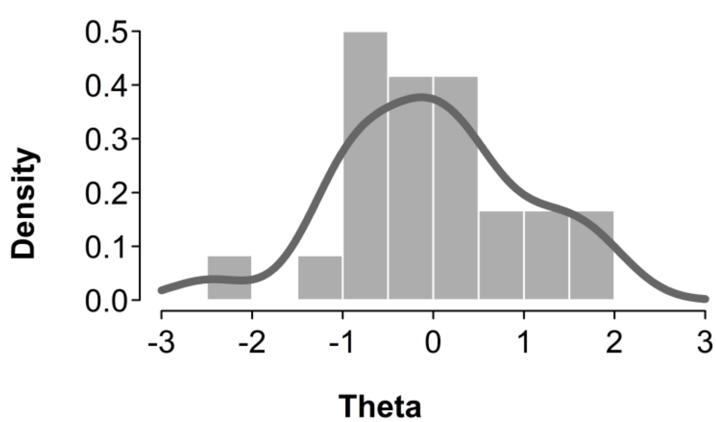


Table 1. Percentiles of thetas

Percentiles	Theta	Theta of the selected individual
…	…	
…	…	
…	…	
100%	1.82	1.82

Table 2. Technical procedures and key results of the example

Sample	N = 24; sex: female = 11 (46%) and male = 13 (54%); course: nursing = 9 (38%) and electrical engineering = 15 (62%); period: 2nd= 21 (88%) and 3rd = 3 (12%); collection approved by the ethics committee of the State University of Santa Cruz, n. 073.11156.2021.0018836-47
Applied vobaulary test	Vocabulary Test 1 measures the crystallized intelligence of the CHC model[27,28]. The test has 24 items. Each item presents one target word and five other words. The respondent's task is to select the word with the closest meaning to the target word. The time limit for the test is 5 minutes. Vocabulary Test 1 is one of 18 tests from the Higher-Order Cognitive Factors Kit (BAFACALO), which has evidence of validity [27,29–35]. The tests are available in Brazilian Portuguese openly and freely to the academic community [1,36–53]. The test was administered virtually through the Psytoolkit platform [54,55].
Software R	The ergodic moment calculation was performed with the linear plateau function of the soiltestcorr package v. 2.1.2[56]. In case of failing convergence, we used the minpack.lm package v. 1.2-3[57] and nls.multstart v. 1.2.0[58]. The Rasch model was estimated with the TAM package v. 4.1.1[59].
Coefficient of determination (R^2) of the ergodic moment estimate for each individual	M = 0.62, SD = 0.36, MIN = 0, Q1 = 0.32, Med = 0.76, Q3 = 0.92 and MAX = 1.
EM of the 24 individuals in the sample	M = 16 points, SD = 3.95, MIN = 6, Q1 = 13, Med = 16, Q3 = 18 and MAX. = 22.
Results of Rasch analysis	Model fit: Test of Global Model Fit (p = 0.1101) and MADaQ3 Statistic and Test of Global Model Fit (p = 0.1238). Infit of items: M = 0.99, SD = 0.13, MIN = 0.75 and MAX = 1.27. Infit of individuals: M = 0.96, SD = 0.21, MIN = 0.64 and MAX = 1.44. EAP reliability = 0.74. Difficulty of items: M = -0.90, SD = 1.27, MIN = -3.48 and MAX. = 1.54. Theta of individuals: M = -0.01, SD = 1.03, MIN = -2.47 and MAX = 1.82.

Conclusion

Whenever we estimate the ergodic moment of an individual, we are estimating the true measure of the individual's ability. In our example, we measured the vocabulary ability which is the individual's ability to understand the meaning of certain words. By estimating the ergodic moment, we estimated the real ability of vocabulary of each individual. In fact, when measuring the vocabulary ability of the individual, we had this individual taken a vocabulary test 10 times, as well as on his reference group, because to transpose the population parameter estimate to any individual in the population, it is mandatory that all individuals in the population have their ergodic moment estimated.

Of course, by asking the individual to take the test 10 times, part of the individual's performance over the course of the test refers to learning. However, this is not a problem. The ergodic moment for performance-based testing is related to learning, but it is not itself the learning. There are individuals who can learn a lot, a little, or not at all. What characterizes the ergodic moment is not the learning to the test, per se, but the moment of the stability of their performance.

To apply the test only once to the individual, assuming that we are measuring the individual is a mistake, because the first measurement of the individual does not represent the individual's ability. In mathematical terms, the individual's first performance on a test only represents a random moment, a point in the random sample of results of the phenomenon measured in the population. If on the first occasion of testing an individual scores 9 points on a test, this represents only one random result of a process in a population to which this individual belongs. Under no circumstances should we assume that 9 points represents the individual's performance. Current clinical practice is based on this mistaken inference. The clinician believes that the patient's 9 points, when he takes a vocabulary test for the first time, represent this individual's performance. The individual's ergodic moment allows us to situate the performance that is properly the individual's. If at his ergodic moment, the individual scores 15 points on the vocabulary test, this is the score that can be assigned to this individual.

In our proposal, we try to establish a procedure that enables the measurement of the individual in clinics, at least as far as performance-based testing is concerned. We hope that our article will encourage researchers to invest in our proposal, criticizing it, improving it, and, mainly, being concerned with this relevant problem.

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