INTEGRATION OF DISTANCE, SLOPE AND FRICTION IN INTUITIVE PHYSICS

Marco Vicentini and Giulio Vidotto
Department of General Psychology, University of Padua, Italy
vicentini@psy.unipd.it

Abstract

The intuitive physics is concerned with the physical knowledge which operates in everyday actions, especially in motor behavior. We evaluate the algebraic structure of motion knowledge which is involved in the task of the inclined plane. We analyze the cognitive integration of three physical factors: distance, slope and friction. Our goal is to determine the function knowledge of common-sense physics, and simultaneously to estimate the parameters for all the unobservable factors. Furthermore, in the integration process, we look for the changing due to the introduction of a third factor. Twenty-four subjects take part to this study. Functional measurement assesses the followed rules as an adding, multiplying, or mixed model (Anderson, 1997). We find the presence of an algebraic rule in motion knowledge. Furthermore, our results suggest that, introducing a third factor, the Integration-Function of many subjects simplifies the task with effortless rules, yielded by some heuristics as well by the averaging rule.

The intuitive or common-sense physics is concerned with the physical knowledge which operates in everyday actions, especially in motor behavior. Typically, intuitive physics regards the physical principles which govern the motions of the objects in the world (Clement, 1983). Intuitive physics blends perception, cognition, and action; it requires the integration of several stimulus factors, a problem to which the information integration theory may be applied (Anderson, 1997; Wilkening, Schwarz, & Rümmele, 1997).

The guiding idea is that the intuitive physics typically depends on multiple stimulus cues which are integrated to determine the overt response. The Integration Function (IF; Anderson, 1996, 2001) occurs within the psychological domain as a constructive process. Stimulus values do not reside in the stimulus itself, but are constructed by the joint process of the external stimulus field and the complexity of the internal background knowledge. IF handles the multiple determination: sensations and perceptions are the integrated resultants of multiple stimulus determinants. This function implies an internal representation which is concerned with the multi-dimensional relation among sensations themselves.

Furthermore, IF provides the base and frame for the measurement. In intuitive physics, psychological measurement is even more important than in traditional psychophysics (Anderson, 1990, 1992). It is possible to estimate both the IF and the psychological values. That is, functional measurement has the capability to determine the function knowledge of intuitive physics and shows that most of the subjects integrate some variables, following exact addition or multiplication rules (Karpp & Anderson, 1997).

Modified inclined plane

In the historical task of the inclined plane proposed by Galileo (1744), subjects estimate how long does it take a ball to roll down an inclined plane. With this task, Galileo proved that falling or rolling objects are accelerated independently of their mass. Anderson (1997) presented this task for the evaluation of the underlying cognitive processes. The experimental question was whether subjects' intuitive guesses about the travel times will exhibit a pattern

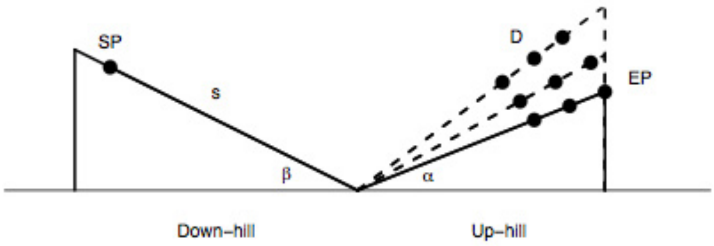

Figure 1: Trolley on a slide: the 3x3 factorial conditions

similar to the one found in nature.

This experiment studies the integration rules which underlie the knowledge of the motion of an object in an inclined plane. This task is based on an experiment proposed by Bozzi (1959; 1998, pp. 296-314). Neither the travel time, nor the estimated ending point is asked to be predicted. In fact, we ask to evaluate the angle of the downhill slope which is necessary for an object placed in a starting point, SP, to roll down the inclined plane for a constant distance, s, to go uphill on an inclined plane, for some distance, D, and to reach an ending point, EP, without passing it. The inclination of the downhill plane is determined by the angle β, and the inclination of the uphill plane by the angle α, as shown in figure 1. Under ideal conditions, where, above all, there is no friction at all, the angle β, required to reach EP, is physical determined by the equation:

$$s \cdot \sin(\beta) = D \cdot \sin(\alpha) \qquad \text{(eq. 1)}$$

If D and α are varied in the factorial design, the factorial graph of the angle β will exhibit a linear fan pattern, prototypical of a multiplicative rule.

This task becomes more complicated when introducing the new factor friction, the force which opposes the relative motion of two surfaces in contact. The coefficient of friction, μ, is a scalar value which describes the ratio of the force of friction between two bodies and the force pressing them together. This coefficient is an empirical measure and cannot be found through calculations. Rougher surfaces tend to have higher values. The value zero means that there is no friction at all. In order to estimate the angle required for our task, it is necessary to introduce some physical concepts, like force, gravity, potential and kinetic energy. Introducing the coefficient of friction in equation 1, it may easily be shown that:

$$s \cdot \left(\sin(\beta) - \mu\cos(\beta)\right) = D \cdot \left(\sin(\alpha) + \mu\cos(\alpha)\right) \qquad \text{(eq. 2)}$$

If μ is introduced in the factorial design, the factorial graph of the angle will still exhibit a linear fan pattern.

Hypothesis

Our hypotheses regard the form of the integration rule implied in motion knowledge. The experimental question concerns the intuitive judgments, whether they exhibit a pattern similar to the one found in nature. Our goal is to establish which algebraic rule is involved in the subject estimation, and simultaneously to estimate the parameters for all the unobservable factors.

According to Bozzi (1998), we expect the observable response R on a linear equal-interval scale, $R = s_0 + w_0 r$, where s_0 and w_0 are zero and unit constants, and r denotes the implicit value of the overt response; furthermore, we look for the presence of the multiplying rule, $r = A \times B$, or the adding one, $r = A + B$, for the integration of the two factors angle and distance. The peculiarity of our task is the introduction of the third factor friction and the analysis of the changes in the integration process due to this new element. Generally, three-factor multiplying models arise occasionally. There are some evidences that subjects may simplify even a three-factor model by adding rather than multiplying (Klitzner & Anderson, 1977). With the introduction of the third factor friction, we expect a full multiplying pattern $r = A \times B \times C$, where A, B, and C are the three factors, or some simpler rules, which could be yielded by some heuristics. Similarly to Singh's results (1990), the integration rules may be mixed, letting both the adding and multiplying operation be within the model, i.e. according to the equation $r = A \times (B + C)$. The integration function of these factors could use only the adding rule, showing a pattern given by $r = A + B + C$. Moreover, some variables might be not considered.

Method

Apparatus

A schematic inclined plane is used. This is a rod on which a marker can be fixed at various distances. No ball rolling occurs because the aim is to study the structure of the knowledge possessed by the subjects, and the specific working rules.

Design and procedure

The general design of this experiment is based on the methods of sub-designs (Anderson, 1982, sect. 2.3.2). This method involves the joint use of sub-designs which omit one or more factors of the full factorial design. This general method provides the complete identifiability of the parameters, adjoining selected sub-designs to a full factorial design. For example, a full three-ways design, A×B×C, may be supplemented with the three two-ways sub-designs.

The experiment consists of two phases, similar in purpose. The common goal is to assess the integration rules. The first phase is aimed to let the subjects familiarize with the task. Distance (19, 24, and 29 cm) × Slope (5, 10, and 15 degrees of the angle) are factorially combined to yield the nine distance-slope stimulus configurations which are shown to the subjects. Each subject judges the configurations in three successive replications. The experimental trials follow immediately the instructions. In the main phase we introduce the third factor friction with three ordinal levels (smooth < medium < rough). That is, the subjects are asked to judge twenty-seven configuration of the three-way design and others three by nine configurations of the two-ways sub-designs, all in three successive replications.

Subjects

Twenty-four subjects, nine females and fifteen males, aged from 18 to 23, take part to the experiment.

Data Analysis

We estimate the parameters for each cognitive model with a procedure implemented in R, similar to the one introduced for the averaging model by Anderson and Zalinski (1990). According to the LS criterion, this procedure provides reliable estimations of the optimal subsets of parameters, for each subject as well for the sample, both from the full factorial design and from the only sub-designs. Moreover, it identifies the involved algebraic rule,

A × B (Trial session)		Design A × B		Design A × C		Design B × C		Whole Design	
Rule	Subject	Rule	Subject	Rule	Subject	Rule	Subject	Rule	Subject
A + B	1, 8, 9, 10, 11, 12, 15, 16, 20, 22	A + B	1, 8, 9, 10, 11, 12, 15, 16, 20, 22, 24	A + C	1, 7, 8, 9, 10, 11, 12, 15, 16, 17, 20, 22, 24	B + C	1, 2, 4, 5, 8, 9, 10, 11, 12, 14, 15, 16, 19, 20, 21, 22, 23, 24	A + B + C	1, 8, 11, 14, 16, 20, 24
								B + C	9, 10, 12, 15, 17
								A + B × C	3, 18
A × B	2, 3, 4, 5, 6, 7, 13, 14, 17, 18, 19, 21, 23, 24	A × B	2, 3, 4, 5, 6, 7, 13, 14, 17, 18, 19, 21, 23	A × C	2, 3, 4, 5, 6, 13, 14, 18, 19, 21, 23	B × C	3, 6, 7, 13, 17, 18	A × B + C	2, 4, 5, 6, 7, 13, 21
								A × (B + C)	19, 23
								A × B × C	*none*

Table 1: Rule assessment with functional measurement theory. In the table there are shown the pooled data for trial session, for each sub-design and for the whole design. Factors are (A) distance, (B) slope, and (C) friction.

assessing different criteria than the ones implemented in Karpp and Anderson (1997): correlation and repeated measures ANOVA. Rule assessment does not seem to be practicable only with these criteria: especially ANOVA implies an additive model, categorical variables, and a unitary design. Actually, cognitive rule generally needs nonlinear weighted models, continuous variables and the integration of several sub-designs (Anderson, 2001). Thus, we implement the conjoint use of several goodness-of-fit indexes, such as adjusted R^2, AIC, and BIC; they provide the capability to account for the complexity of the whole design, and simultaneously to select the most suitable cognitive model.

Results and Discussion

Two-ways sessions

Repeated measures ANOVA was applied separately to the data of each subject, using the level of significance $\alpha = 0.05$. All subjects recognize the different kinds of friction and the differences among the factor distance and slope. Functional measurement shows that all subjects use an algebraic rule to represent the joint effect of the two physical variables. As outlined in table 1, the functional measurement shows that the multiplication rule is more frequent for the two-ways designs, except for the integration of factors slope with friction; this result supports the general idea that most of the subjects use the physically correct multiplying rule for the task. Some difficulties may be encountered in the integration of the factor friction.

Table 1 shows the rules involved by each subject. Only one subject shows a different pattern from the trial session to the first two-ways design. Eight subjects adopt both an adding and multiplying rule. The remaining fourteen subjects maintain the same integration rule from the trial session through all the two-ways designs. This is a very important result, because it supports the idea that the subjects adopt a common rule for the integration of different physical factors.

Main Design

The evaluation of the full three-ways design mostly changes the integration process. No subject adopts the physics-multiplying rule for the conjoint integration of the three factors. Five subjects account for two variables only, without regarding the factor distance. The goodness-of-fit indexes suggest that the majority of subjects integrate the factors with an additive rule, excluding any interaction or weighting process. The pooled data for these additive subjects are shown in figure 2. Besides, eleven subjects involve complex rules, which include the integration of several algebraic rules and various priorities.

This may represent deep cognitive processes but it may also let hypothesize some averaging rules, as proposed by Anderson. Figure 3 shows the data-plot for these subjects: the graph reveals a linear fan pattern, which can be the expression of the underling multiplying role; but it also may support some interaction effects, which can be due to averaging processes. Thus, a comparison between the goodness of fit indexes provided by the mixed model and the ones provided by the averaging model may be required.

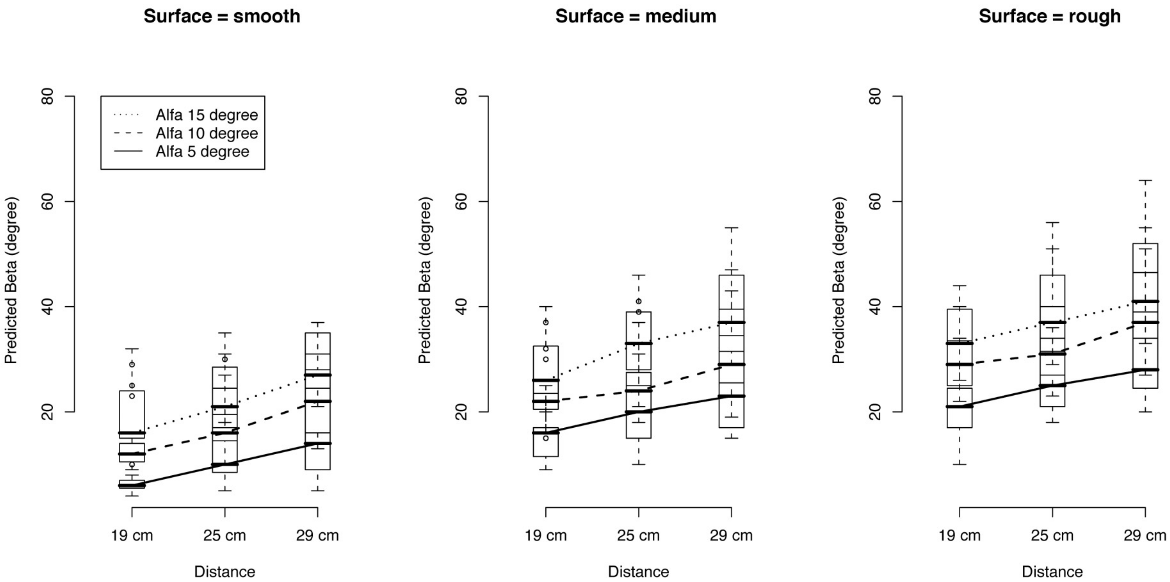

Figure 2: Box-plot of the pooled data from the additive-rule subjects.

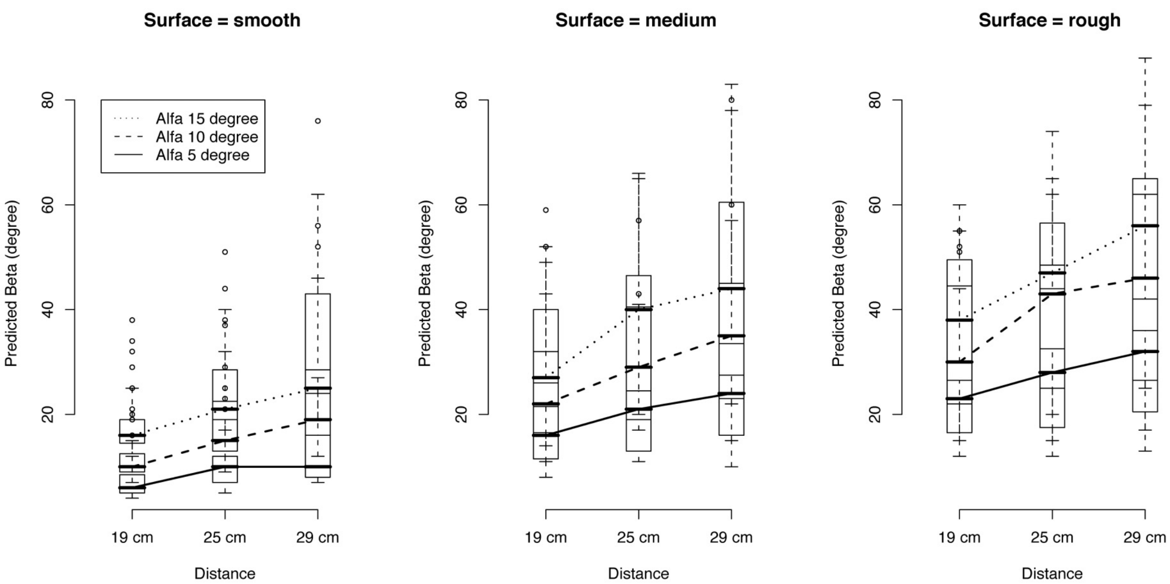

Figure 3: *Box-plot of the pooled data from the mixed-rule subjects.*

Conclusions

In this experiment we applied the functional measurement theory to the estimation of the involved psychological values and to the selection of the concerned cognitive rule. Our procedure gives more information than the only repeated measures ANOVA, especially for the estimation of all the parameters of the cognitive models.

Furthermore, we evaluate the function knowledge with the single subject analysis. According to Karpp and Anderson (1997), the information integration theory can provide a correct assessment of function knowledge especially for the single subjects and then for groups. In addiction, we get some evidences to hypothesize the presence of the averaging rule almost for some subjects, when integrating more than two physical factors.

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