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Heuristics and invariants in dynamic event perception: Immunized concepts or nonstatements?

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There is ample evidence showing that observers are able to judge dynamic properties of moving objects on the basis of visual kinematics. It is, however, widely disputed as to how to explain this body of data. While direct perceptionists claim that observers have direct access to the underlying dynamics of the event (kinematic specification of dynamics, or KSD, principle), contenders of the perceptual heuristics approach (PH) suggest that observers use the visual equivalent of a heuristic to arrive at their judgments about dynamics. First, the critical assumptions of the KSD principle are discussed in order to motivate the claim that the KSD principle cannot be falsified and is thus immune to empirical criticism. Then the same scrutiny is applied to the PH approach. It is, in its general form at least, afflicted with a similar lack of falsifiability. In comparing the concepts underlying invariants and perceptual heuristics, my conclusion is that a critical experiment aimed at deciding between the two approaches is impossible, and that KSD and PH can be regarded as nonstatements. The findings reported in the event-perception literature must therefore be reevaluated on these grounds.

Recently, a heated debate has developed about the best way to conceptualize human perception of dynamic events. Dynamic events are the events that physicists group together in the field of classical mechanics which they describe by using such concepts as mass, force, conservation of momentum, and energy. The collision of two billiard balls would be an example of such an event. From a perceptual point of view, the involved variables are not as easily accessible as are such nondynamic variables as size, length, or color. Nonetheless, many everyday situations require that we make judgments about dynamic events.

The debate at issue concerns the psychological basis for judgments made in such situations. Runeson (1977) and his colleagues have argued that dynamic variables can be perceived directly and that they have the status of a perceptual invariant, as defined by J. J. Gibson (1979). Proffitt and Gilden (1989), on the other hand, have claimed that observers resort to the use of heuristics, or rules of thumb, when judging dynamic events. In what follows, I review both positions with emphasis on the theoretical claims made by each camp. I will show that the theoretical frameworks associated with these positions, the principle of direct perception as well as the notion of perceptual heuristics, share a potentially serious shortcoming: they are immune to empirical testing and cannot—as a matter of principle—be falsified. Both approaches are then interpreted in a new light, using a less traditional theory of science, the nonstatement view. This exercise has significance beyond the realm of event perception. The lack of falsifiability is symptomatic not just for positions of direct versus indirect perception; it also appears to be a general problem of many theories in cognitive psychology.

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Dynamic Event Perception

The notion that higher order attributes of events can be perceived on the basis of simple motions has been considered as commonsensical since such classic demonstrations as those of Heider and Simmel (1944) and Michotte (1946/1963). Heider and Simmel showed that intentions were spontaneously attributed to moving geometrical shapes that followed specific acceleration patterns. Michotte reported that, when shown synchronized approach and separation of line segments, observers reported compelling impressions of causality. These demonstrations, along with more rigorous studies of dynamic event perception (J. J. Gibson, 1979; Johansson, 1950), promote the position that impressions of force, causality, and so forth, are unmediated, direct perceptual qualities.

The most specific and influential approach to dynamic event perception that grew out of this tradition is the principle of kinematic specification of dynamics (KSD). Roughly, the principle states that these unmediated perceptual qualities emerge when the dynamics of a situation is sufficiently specified by its kinematics (Runeson, 1977; Runeson & Frykholm, 1983). Kinematics can be thought of as geometrical descriptions of motion (and accordingly changes in the optic array) based solely on

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length and time parameters, not on mass or forces. That is, if the kinematic motion can, in theory, belong to only one particular dynamic event, observers should be able to "see" the dynamics. For example, in the case of two colliding billiard balls, the specific velocity changes of incoming and exiting balls can be obtained with only one particular mass ratio. KSD claims that people perceive the mass ratio directly, on the basis of the kinematics of the event (i.e., changes in the velocity vectors between pre- and postcollision phases).

Perceptual theories that propose indirect perceptual mechanisms have a longer tradition than do theories of direct perception. For example, the idea that people use unconscious inferences to arrive at their final percepts was suggested by Helmholtz (1866) and continues to receive strong support (e.g., Rock, 1983). However, indirect perception was not proposed as a candidate for dynamic event perception until recently (Gilden, 1991; Proffitt & Gilden, 1989; Todd & Warren, 1982). Dynamic event perception originally was the domain of direct perceptionists, and it took a chastened Gibsonian view to suggest an indirect approach to the field. Gilden and Proffitt (1989) proposed an indirect hypothesis for event perception in the context of planar collisions, suggesting that in the case of two colliding objects, such as two air hockey pucks, observers base their judgments on simple heuristics. One reasonably successful heuristic would be to judge the puck that exits fastest after collision to be lighter than the slower object (Gilden & Proffitt, 1989). The general interpretation that, when asked to make visual judgments of dynamic events, observers are believed to take a reduced aspect of the kinematic information that is available to them and typically apply an oversimplified heuristic to it will henceforth be called the perceptual heuristics (PH) approach.

Inasmuch as the introduction of heuristics constituted the first serious challenge within the field of event perception, it was met with fierce criticism.[1] In the eyes of some direct perceptionists, the notion that observers use simple-minded heuristics (Gilden & Proffitt, 1994) is "no doubt false" (Runeson & Vedeler, 1993, p. 618). PH contenders are equally assertive, stating that the KSD principle "is either wrong or unsupported by the data" (Gilden, 1991, p. 556). Irreconcilable as these positions seem and notwithstanding the theoretical differences between the general ideas behind the two approaches, the differences between them are much less demonstrable than is assumed on both sides of the debate. The fact that observers, to some extent, are able to extract dynamic properties of moving objects on the basis of visual kinematics is undisputed, but empirical tests that attempt to decide for or against either approach may be futile. The major difference between the positions is an epistemological one, and much of the debate ignores this fact. The following paragraphs scrutinize the theoretical claims that can be made on the basis of KSD and PH, suggesting that the two approaches have more in common than meets the eye; at least in their general interpretations, both cannot be falsified and both have to be regarded as prototheoretical frameworks. The controversy cannot be about the truth of one approach versus the other; it can only be about which one provides a more useful framework within which to describe dynamic event perception.

A Note on Falsifiability and Truth Values

To demonstrate why the two major approaches to dynamic event perception cannot in principle be falsified, it is useful to review the nature of psychological theories and empirical statements. If scientific knowledge is the orderly accumulation of true statements about a subject, it becomes important to scrutinize potential statements in terms of their truth values. Mainstream psychology seems to adopt, if implicitly, a stance that is more or less congruent with the falsificationist position, which was initiated by Popper (1935). According to this position, scientific statements have to meet at least two criteria. (1) *Generality*: The events covered must be independent of time and place; for example, the statement that last week person X was able to correctly predict the trajectory of a falling object is not a hypothesis because it lacks generality, as do most historical statements. (2) *Falsifiability*: The statement must have a chance to be false; the statement that observers may make mistakes cannot be falsified unless it is specified under what circumstances they do and do not make mistakes. Thus, the most powerful hypothesis is one that is very general in its scope and easy to falsify. Even though it was developed at the beginning of the century, falsificationism, or logical positivism as it is often called, remains the most influential metatheory in cognitive science. None of its successors have been able to gain nearly as broad an acceptance (see Bechtel, 1988).

Supporters of both PH and KSD appear to espouse a falsificationist view, at least when it comes to judging the opponent. For instance, Gilden (1991) states that the "falsehood of KSD" (p. 555) in general would be shown if mass ratio judgments in collisions were unrelated to momentum conservation. Likewise, Runeson (1995) claims that he has found a clear counterexample to the PH model obtaining a better fit of collision judgments data with true mass ratio than with either of the heuristics suggested by Gilden and Proffitt (1989, 1994). This appeal to falsifying observations on both sides justifies a judgment of both approaches from a falsificationist point of view and a scrutiny of whether or not they satisfy the criteria upheld by a falsificationist view.

KINEMATIC SPECIFICATION OF DYNAMICS

The principle of KSD claims that in cases where the dynamics of an event are sufficiently and uniquely specified by visual kinematic information, people are able to take advantage of this relationship and make unmediated judgments about the event dynamics. There is evidence that observers are able to make judgments in agreement with this principle. For example, Warren, Kim, and Husney (1987) showed that people can judge the elasticity of a bouncing ball on the basis of relative height from one bounce to the next or on the basis of period shortening between bounces. However, to be of theoretical interest, the principle must claim more than the existence of some instances in agreement with it. KSD has been taken to postulate that observers always pick up the dynamics of any given situation as soon as it is sufficiently determined by its kinematics (Gilden, 1991); however, this strong claim of a priori attunement has lost its supporters.

Typically, KSD is qualified by the necessity of perceptual attunement to the relevant kinematics. Just as observers are believed to become attuned to such invariants as time-to-contact (the rate of retinal object dilation over time increases as an object approaches the observer), they have to become attuned to the information that is relevant in any given dynamic event. The notion of attunement is critical for an evaluation of the KSD approach. While it is understood that attunement has to occur before reliable judgments can be made, tangible criteria for attunement seem to exist only in the domain of early perceptual development (E. J. Gibson, 1969). According to E. J. Gibson's suggestions, attunement is brought about by a process of perceptual learning and differentiation. With experience, perceptual invariants can be extracted more reliably and with greater differentiation.

The intervening process of attunement puts severe limitations on the generality of the KSD principle. Even if the dynamics of an event are uniquely specified by its kinematics, predictions about perceived dynamics cannot be made unless additional hypotheses about the observer's state of attunement are made. However, if the state of attunement is defined as a function of perceptual success while perceptual ability is explained by attunement, we run into a serious circularity problem. It can be overcome only when the presence of attunement is assessed independently from the perceptual achievements that it is supposed to explain. Hence, the concept of attunement would benefit tremendously from an addition of explicit criteria that are sufficient (and, ideally, also necessary) for an observer to become attuned. Meanwhile, an empirical test of the KSD principle hinges on assumptions about whether or not sufficient exposure to the relevant class of events has occurred.

Strong and Weak Versions of KSD

A strong version of the KSD principle would claim that every adult is able to pick up the invariant information contained in those dynamic events that make up our natural environment. In other words, an omnibus attunement occurs during childhood. This reading of the KSD principle is falsified because there are cases where observers make erroneous judgments even though the dynamics of the situation are specified kinematically. For example, observers are notoriously bad when judging events that involve accelerated motions. They do not appreciate the quadratic relationship between tether length and period of a pendulum (Pittenger, 1990) or the coupling between rotation and translation of wheels rolling down an incline (Hecht, 1993a). Consequently, such a strong version of the principle is not seriously entertained even though it has the advantage of needing no further criteria for attunement.

The weaker and more interesting version of KSD proposes that it is *possible* for observers to pick up the dynamics of kinematically specified events. That is, as long as the proximal stimuli on the retina contain enough information to reconstruct the dynamic properties of the observed event, observers can learn to do so. They can pick up the decisive higher order invariants. To test the validity of the thus qualified KSD principle, one needs to provide the observer with sufficient opportunity to judge and manipulate complex events. KSD would be refuted only if extensive training (within an ecological action context) failed to enable the observer to become perceptually attuned to the relevant kinematic invariant.

This weaker version of the principle comes close to its original format as proposed by Runeson and Frykholm (1981, 1983), who suggested that movements can often specify the causal factors of events. For example, observers could accurately estimate the weight of a box that was being picked up by an actor. They did so on the basis of purely kinematic information. All they saw was a set of point-lights that were placed on the actor's joints and on some locations on the box; hence, no direct information about weight was preserved in the display even though it was kinematically specified. Observers had to extract the weight information from the point-lights they saw and the natural constraints on human joint movements and limb lengths.

However, the weak version of KSD is fraught with two serious problems. First, the only support for KSD is gained from rather simple motion contexts, and there is evidence (Gilden, 1991) for poor performance in more complex cases (multidimensional events). Second, thus far, no criteria have been suggested to determine when sufficient opportunity for attunement has been given. Thus, the weak KSD principle can always be defended against empirical findings of poor performance. Runeson and Vedeler (1993) realize this conceptual shortcoming of the KSD principle and concede that KSD is not a "comprehensive theory" (p. 617) but a principle. What, then, is the scientific status of this principle? In the next paragraphs, an attempt is made to answer this question with a theoretical evaluation of the weaker version of the KSD principle.

The Theoretical Status of KSD

To properly evaluate the KSD approach, the various dynamic events that it applies to have to be contrasted with the potential empirical outcomes. The criterion of falsifiability is satisfied only if at least one potential empirical outcome can be named that would contradict the theory. To determine whether this is the case, consider a two-dimensional event space consisting of the nature of the dynamic event and of observer performance (see Figure 1). To describe the dynamic event, I borrow the notion of event "complexity" from Proffitt and Gilden (1989), which is based on the physics of the event.[2]

Kinematic Specification of Dynamics (KSD)

Event-Complexity

Performance	1-D	multi-D
erroneous	A: approach falsified B: immunization strategies	A: dynamics not sufficiently specified B: attunement not yet achieved
accurate	appropriate attunement	appropriate attunement

Figure 1. Juxtaposition of possible empirical outcomes and explanations that are conceivable on the basis of the KSD principle for dynamic events of varying complexity. Only erroneous performance could falsify the approach.

Complexity or dimensionality of a motion context is a function of how many attributes (e.g., position, mass, shape, size, orientation) of an object influence its motion. Extended body motions are multidimensional because more than one category of information influences the motion trajectories. A wheel rolling down an inclined plane is an example for such an event: mass distribution within the wheel and length and slope of the incline are the categories of information needed to determine how long it will take for the wheel to get to the bottom of the ramp. Objects within particle motion contexts can be adequately described in terms of the motion of their centers of gravity; they are one-dimensional. An object in free fall is an example of such a one-dimensional motion context. Its only relevant dimension, release height, determines when it will hit the ground (setting aside effects of air resistance).

The other dimension needed to evaluate the falsifiability of KSD concerns the possible empirical outcomes (accurate vs. erroneous) in observations of simple and complex events. Interestingly, the KSD only predicts accurate performance via perceptual attunement. It focuses on what people can do and neglects what they cannot do. Accordingly, correct judgments can always be taken as support for the KSD principle. If observers are able to judge simple or complex events, one can always cite appropriate perceptual attunement as the reason.

The more interesting cases of potentially falsifying observations are thus to be found exclusively in the case of erroneous judgments. An error can be defined as the failure to see (or judge) the dynamics of an event even though the kinematic information specifying it could in principle be detected by the observer. For example, seeing the spin on a billiard ball or watching a gyroscope does not seem to give us an appreciation of their dynamics. In the case of such complex events (Figure 1, top right panel), erroneous performance is easily explained by an insufficiency of attunement. Although nobody would seriously expect people to become attuned to such complex dynamics, KSD claims that it is possible. However, as long as the theory does not include criteria about when such attunement should be achieved, failure to judge complex dynamic events accurately cannot be used as evidence against KSD. Moreover, when considering highly complex events, direct perceptionists would not expect attunement, because such events would be classified as ecologically invalid.

Thus, only the case of erroneous performance in relatively simple event contexts could seriously challenge KSD (top left panel). Such cases have certainly been reported. One example would be the fact that even though people see, on a daily basis, that the surface of water in a closed container remains invariably horizontal, they still make judgment errors, accepting tilted water levels as being perfectly natural. More importantly, waitresses and bartenders with extensive experience make even larger errors than less experienced subjects (Hecht & Proffitt, 1995). Obviously, experience does not always lead to attunement and can even have adverse effects, even in very simple contexts. However, such outcomes are still not taken to falsify the KSD principle, because the invariant at issue may have been incomplete (Runeson, 1989).

There are two reasons for the existence of incomplete invariants. First, people could become attuned to only one aspect of an event. Normal attunement that one would expect in simple situations could go astray. Second, it may be faster and sufficiently accurate to use an incomplete invariant instead of a complete one. "Whenever performance differs systematically from perfection, this is ... because the perceiver is relying on an *incomplete invariant*" (Runeson & Vedeler, 1993, p. 624). While the concept of incomplete invariants is not fully developed, it does constitute an immunization of the KSD principle against any serious attempt at falsification. What makes it worse is that even if the shortcomings in the top right panel of Figure 1 (underspecification of attunement criteria) are overcome, the notion of an incomplete invariant would also cover that quadrant of the wager in terms of its power to immunize.

The concept of immunization was originally put forth as a criticism, from a falsificationist point of view, against incomplete theories, which predict outcomes based only on sufficient, but not also on necessary, conditions (Münch, 1973). In the case of KSD, the notion of incomplete invariants constitutes quite a different and more radical immunization: all possible outcomes are covered by the theory. It is hard to imagine a situation in which the incompleteness argument could not be put forth. Runeson (1989) states that incomplete invariants are "a conceptual tool for handling cases of situation-specific perceptual proficiency as well as cases of generally low or intermediate levels of performance" (p. 8). He seems to acknowledge the lack of falsifiability of this position and does not consider KSD as a theory in the strict sense of the word. Yet Gilden (1991) thinks there is evidence that the KSD principle (in its weaker form) has been falsified.

In conclusion, despite its great intuitive appeal, the weak version of the KSD principle in its present format has to be considered as being impossible to falsify. Accurate performance is evidence for attunement, and the principle is immunized against all forms of erroneous performance. Unfortunately, a statement that cannot be falsified, according to Popper (1935), has no explanatory power whatsoever.

PERCEPTUAL HEURISTICS

General Description

In contrast to KSD, the heuristic account of dynamic event perception is based on the idea that judgments of dynamic events are based on separate rules that people have about the workings of the world. A lawful relationship between kinematics and dynamics is neither required nor assumed here. The rules that people apply are informal and seem to be related to the notion of procedural (as opposed to declarative) knowledge (Anderson, 1982). Such rules were first suggested under the term "heuristics" by Todd and Warren (1982; Todd, 1981). They were then understood as more or less unconscious perceptual heuristics (Gilden & Proffitt, 1989; Proffitt & Gilden, 1989) but eventually were specified as rules that work upon data obtained from perceptual event segmentation and from world knowledge (Gilden, 1991).

Two notions related to the concept of PH deserve particular consideration since they become crucial in an evaluation of the approach: event complexity and perceptual salience. On the basis of their definition of event complexity as described above, Proffitt and Gilden (1989) have collected strong evidence that novice observers are very good at judging the dynamics of particle motions (one-dimensional; 1-D) as long as they do not misconstrue them as being multidimensional. Thus, the core of the PH approach states that judgments of dynamic events are correct as long as only one dynamically relevant object parameter is physically involved and at the same time perceptually processed.

Our judgments of multidimensional motions, on the other hand, are thought to be very limited. Be it gyroscopes, balances, colliding objects, volume displacements, or rolling wheels, untrained observers do not seem to be able to accurately integrate the relevant variables. Instead, they behave as if they picked the most salient dimension and applied a heuristic that was based on it, thereby neglecting all other less salient factors. For example, Proffitt, Kaiser, and Whelan (1990), in studying people's understanding of rolling wheels, found that novices performed poorly when they were asked to tell which of two wheels would roll down an incline fastest, as did physicists when they made quick, intuitive judgments. When both wheels are released simultaneously at the top of the incline, mass distribution is the only variable that influences the acceleration of the wheel. Mass and radius are irrelevant dimensions. The problem can be thought of as analogous to a pirouetting ice skater who starts to spin faster if she pulls in her arms and thus distributes her mass toward the axis of rotation. The potential problems associated with the use of the salience concept and the possibility of misconstrual of 1-D events are discussed in the next section.

Another feature and potential problem of the PH approach is the somewhat blurred status of heuristics with respect to direct perceptual versus higher order cognitive processes. The characterization of heuristics as "simple-minded ideas" that people use when making dynamic judgments (Gilden & Proffitt, 1994) suggests a concept similar to that from which the name was borrowed (Tversky & Kahneman, 1974). Gilden (1991) embeds the PH concept into one of decision theory even closer to the original Tversky and Kahneman idea. However, at the same time, PH are never explicitly treated as conscious rules. If they were, all cases indicating that people's beliefs often are at odds with their perceptual performance (e.g., the straight-down belief: McCloskey, Washburn, & Felch, 1983; Kaiser, Proffitt, Whelan, & Hecht, 1992) would become highly problematic. Thus, a perceptual heuristic appears to be a way to describe a visual process that produces dynamic event properties which may or may not be mediated or nondirect. People behave only *as if* they were using heuristics.

The Theoretical Status of PH

Since the choice of the term "heuristic" suggests a universal or at least general process of perception, which is not necessarily limited to dynamic events, the following paragraphs evaluate the PH approach in its general interpretation. Notwithstanding the testable predictions made by the hypotheses in the collision experiments of Gilden and Proffitt (1989), the general concept of perceptual heuristics is not falsifiable.[3]

To assess whether the PH approach satisfies the criterion of falsifiability, the matrix of event complexity by empirical performance to be scrutinized will be the same as that used above for KSD. The potential power of PH lies in the fact that, unlike the KSD principle, it has a prediction for errors as well as for accurate judgments. Unlike attunement, heuristics can be wrong. They can also be correct but inappropriate. For example, the heuristic that moving and spinning balls curve is correct and appropriate for a tennis slice but wrong for an ice hockey puck.

Figure 2 shows the possible empirical outcomes from a PH point of view. When observers perform accurately in judging simple events, it is usually easy to point out a simple rule of thumb that people might use (bottom left panel). A more interesting case arises when observers err in this situation (top left panel). Here PH would claim that observers have used an inappropriate heuristic. For example, if an object made of steel is judged to fall faster than an object made of wood (setting aside air resistance),

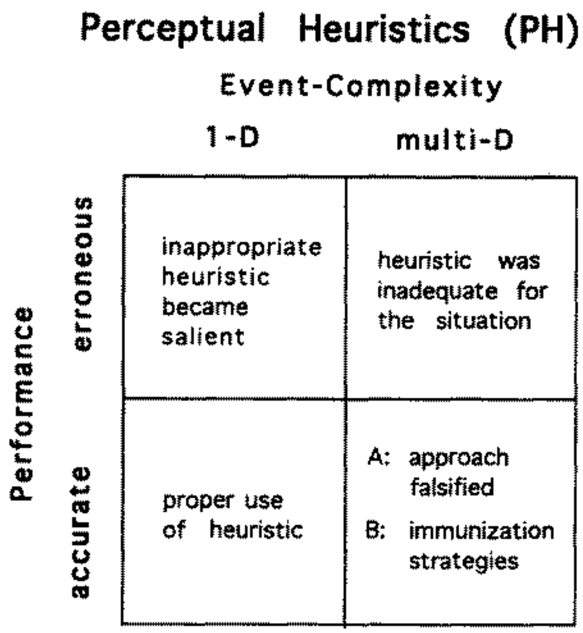

Figure 2. Possible empirical outcomes and conceivable explanations that are based on the PH view. Only accurate performance in complex situations could falsify the approach.

a wrong heuristic is at work. The potential problem that observers often explicitly know the correct heuristic but fail to use it is overcome by allowing perceptual heuristics to be unconscious (Proffitt & Gilden, 1989). Thus, the heuristic can—but need not—contradict explicit world knowledge. Cases like the water-level problem fall into this category. Many observers, even though they know that water surfaces are invariably horizontal, behave as if they do not know this principle when given the perceptual task of adjusting or drawing the water level in a tilted beaker (e.g., McAfee & Proffitt, 1991).

What makes these and other results worthless for a test of the PH approach is due to the following circularity problem. The existence of a perceptual heuristic, which could be unconscious, can be established only via perceptual performance. Thus, poor performance is taken to be evidence for the fact that the observer used no PH or used an inappropriate one. The adoption of an inappropriate heuristic, in turn, is used to explain the poor performance. This circularity problem applies whenever observers show erroneous performance and only one heuristic is involved. As a way out of this dilemma, one could conceive of a theory of salience that defined the most important parameter, based on the physics of the situation, and then specify *one* heuristic based on this parameter. Proffitt and Gilden (1989) might have had something like this in mind, but their concept of salience is insufficiently specified within the PH approach. Moreover, it is not clear if even a strong theory of salience could completely overcome the problem. One would have to rule out an observer's using a wrong heuristic based on an appropriate physical parameter. Thus, at least without additions to the approach, erroneous performance in simple situational contexts can always be interpreted as being supportive of PH.

In cases where the dynamic event is more complex (top right panel of Figure 2), the PH view has no trouble explaining why, for example, the forces acting on a precessing gyroscope fail to be appreciated perceptually. People simply do not have any heuristic they can relate to the event (e.g., Kaiser et al., 1992). In less complex but still multidimensional cases, the situation becomes more interesting. Suppose it can be shown that, in isolation, people use heuristics A and B. If a more complex event is judged erroneously, one that is adequately described by A, B, and a combination rule, people must fail to integrate the two heuristics A and B. However, this conclusion cannot be drawn: PH theory does not posit that if people use heuristics A and B in simple circumstances, one or the other comes to bear in the complex event. It is permissible that observers mistakenly choose a third heuristic, which is not appropriate.

The acid test for the PH approach is the use of complex situations in which observers perform well (bottom right panel of Figure 2). In the case of collision events, Runeson and Vedeler (1993) argue that their observers perform at a level of accuracy that refutes PH and supports the KSD principle. Gilden and Proffitt (1994) disagree and argue that individual observers clearly fall into groups that use one or the other heuristic, while performance averaged across a larger sample looks deceivingly accurate. Be that as it may, in other situations observers undoubtedly process visual information to a degree that precludes the use of simple heuristics. It is hard to conceive of how a tennis player would be able to judge the future position of the slice ball on the basis of a heuristic that involved only one parameter. Likewise, professional billiard players are able to predict the path of spinning billiard balls with amazing accuracy on the basis of visual information alone (Hecht, 1993b). Taken together, the evidence and plausibility for accurate perceptual judgments of complex events should suffice to falsify the approach in its general reading.

However, there are two reasons for why accurate judgments in multidimensional situations may even be considered to be compatible with the PH approach. First, observers could have learned to integrate several heuristics. In cases where the successful use of two separate heuristics is compatible with performance data, it is conceivable that observers use a smart combination rule that combines the heuristics according to some weighting function. Especially in cases of highly skilled perceptual behavior, as in tennis or billiards, it is plausible that while unskilled observers exclusively use one heuristic, better trained observers are able to integrate two or more heuristics. Proffitt and Gilden (1989) do not consider this possibility, and it would considerably dilute their central claim that observers use only one salient "parameter of information" (p. 384).

A second alternative could exploit the fact that the concept of an information parameter might be stretched to accommodate a Gibsonian invariant. This becomes apparent in the current dispute about collision dynamics. The relative velocity changes of the balls before and after collision map into the mass ratio of the two objects. A given heuristic will be more or less successful depending on what aspect of the velocity changes it is based. A heuristic could be based on a mere comparison of postcollision speeds or angles (Gilden & Proffitt, 1994), but it could also be based on velocity vectors—or could it? A heuristic obviously has to be based on a quantitative parameter. But it is not part of the concept of how simple or complex this parameter has to be.[4] Can a heuristic—thus shifted from a qualitative concept to a quantitative one—still be distinguished from an invariant? Especially if the parameter is not completely simple, the borders between an incomplete invariant and a heuristic based on a somewhat complex parameter seem to become very fuzzy.

Either one of the above alternatives would rescue the PH approach, but they have the side effect of rendering it immune to falsification. Since good performance in complex events was the only remaining empirical finding that could refute the approach (bottom right quadrant of Figure 2), PH in its general form explains all possible outcomes. This immunity turns into perfection once the idea of nonelementary heuristics is entertained explicitly (Braunstein, 1994). Even Runeson (1995) no longer sees a difference between such a sophisticated heuristic and an incomplete invariant.

KSD VERSUS PH

Taken together, the preceding sections allow for a quite devastating conclusion: despite their vastly different appearances, KSD and PH share the calamity that they are immune to falsification. Given this outcome of the above analysis, the recent controversy between KSD and PH supporters appears to be moot. In essence, Runeson and Vedeler (1993) pronounce PH as being falsified, but to do so they have to impose an extreme interpretation on the term heuristic. Likewise, Gilden and Proffitt (1994) believe that the KSD principle is falsified. Gilden (1991) argues that observer judgments about collisions are not parametrically related to the kinematics, and that therefore KSD must be wrong. However, this holds only for the strong version of the KSD principle, which is refuted by the bimodal distribution of performance in cases of collisions (good with large variations of postcollision velocities, poor when velocity and angle are moderate).

The weaker version of KSD, however, which allows incomplete invariants, is alive and well. In the case of the complex invariant that specifies mass ratio (consisting of initial velocities, final velocities, collision angle, and exit angle between the objects), it is not unreasonable to assume that observers map one aspect of the kinematic situation onto their dynamic impressions (i.e., use an incomplete invariant). This incomplete mapping appears to be exactly what Proffitt and Gilden (1989) describe as a perceptual heuristic. Thus, the two approaches seem to be in perfect agreement with regard to the data. They also have commonality concerning their theory structure in that they both suffer from a circularity problem. For KSD, good performance is evidence for attunement, which in turn produces good performance. For PH, poor performance is evidence for the use of heuristics, which in turn is taken to produce poor performance.

There seem to be only two distinguishing features of the competing approaches—namely, the language used by each camp and the differential treatment of supporting and contradictory evidence. While applying a moderate— and ultimately truistic—interpretation to their own approach, each side creates a straw man of the opposing side, which they then destroy. The moderate version of the respective opponent's theory is conveniently ignored. In principle, there is nothing to be said against this method as long as it is identified as an illustrative technique. When concerned with the true state of affairs, however, both sides should acknowledge that what they are proposing are "theories" that do not require empirical testing.

Proponents of both approaches seem to realize the shortcomings of data interpretations from the other approach: Gilden (1991) correctly observed that behavior consistent with the hypothesis of a perceptual invariant does not mean that people actually base their judgments on this invariant. There may be some perceptual cues confounded with it that observers use instead. Runeson (1989) argued, conversely, that just because observers behave in accordance with a particular heuristic does not mean that they do in fact base their decisions on one. It is ironic that both camps demand that the opposing camp bring proof that it is the invariant or the heuristic that people are using, while not demanding similarly rigorous proofs for their own positions. If they did so, they might notice the impossibility of such proof because both approaches are in principle not falsifiable. However, this is not to say that a particular heuristic cannot be disproved or a particular invariant cannot be shown to be neglected.

It may be of historical interest to determine why the two approaches clash despite their immunity to falsification. The answer probably lies in a positivistic tendency by all involved theoreticians to seek evidence in favor of their respective theories. In fact, PH proponents focus on examples of cases where people are at a loss when judging complex events, while KSD supporters look for cases where observers perform well, which are events of relatively low complexity. For example, PH studies tend to look at judgment errors as a function of visual anomalies, whereas KSD studies tend to look for what parameters get extracted when naturalistic dynamic events are successfully viewed (Kaiser, in press). The notable domain of overlap of research between the two approaches is that of planar collisions. And this is where KSD and PH outspokenly disagree. It might also be that the agreement of some data with a *specific* heuristic or a *specific* invariant is generalized and taken to verify the whole approach, which would make for a regression to the prepositivist evaluation of theories.

Can two nonfalsifiable theories be in disagreement? They can. Being nonfalsifiable does not mean that a statement is analytically true or devoid of psychological content. The fact that no empirical *experimentum crucis* between the approaches is possible does not mean that they cannot contradict each other. They postulate different mechanisms which are untestable with pure performance measures. It is impossible to decide—on the basis of performance data—whether an invariant has been extracted from the kinematics of an event or whether observers have used (unconscious) rules of thumb. Nonetheless, heuristic usage of information is incompatible with KSD.

A STRUCTURALIST SOLUTION?

The analysis can be summarized as follows. There are two more or less incompatible approaches that attempt to explain how people make visual judgments about events. The empirical data that are available and are not objects of disagreement between the two camps are compatible with both approaches to the extent that neither qualifies as a theory in the traditional falsificationist sense of the word. A dogmatic falsificationist would have to dismiss both approaches, and probably many other theories in cognitive psychology, as tautologies that do not satisfy the basic criteria for scientific theories (Popper, 1935). However, a structuralist philosophy of science, which has only recently been applied to psychological theories (Westmeyer, 1989), posits that the core of a theory is not only immunizable but is immune to begin with, thus turning the plight into a feature.

This nonstatement view was founded by Sneed (1971) and elaborated by Stegmüller (e.g., 1979; for a recent overview see Balzer, Moulines, & Sneed, 1987) and is basically a set-theoretical description of theories. The main argument is that an insurmountable circularity between observation and theory necessarily turns theories into nonstatements: all experience has to rely on theoretical assumptions (such as theories about instruments that are used in observation or theories about perception), while at the same time, all theories depend on observation.[5] The structuralist solution consists in the rational reconstruction of a theory based on a set-theoretic axiomatization.

Most—if not all—theories are interpretable as reconstructions of a reality whose central premises are nonstatements. One or more concepts form the core of such a reconstruction and have to be accompanied by a set of intended applications. The structuralist position, or nonstatement view, does not accept empirical data as proof but rather as indications, because a given reality is part of the (re)constructive process and not independent of it (Pearce, 1981).

The great advantage of the structuralist position is that, unlike the statement view of traditional theories of science, it retraces and furthers evolutionary theory development. Where falsificationism leaves the creation of theories up to chance and proposes a criterion only to weed out false theories, the nonstatement view allows one to preserve the theoretical core of a given theory while its intended applications change. One of the main differences between the two metatheoretic positions is that logical positivism treats observational terms as strictly nontheoretical, whereas the nonstatement view defines observational and theoretical terms as orthogonal dimensions (Westmeyer, 1989). Thus, structuralism is particularly useful when dealing with psychological concepts or intervening variables, such as the concept of a heuristic. The nonstatement view can also be characterized as replacing the Popperian criteria of generality and falsifiability with such criteria as consistency, elegance, and economy.

The specific nonstatements concerning the perception of dynamics could be phrased according to either PH or KSD terminology. It would be a matter of the intended applications as to whether one or the other reconstruction was chosen. Instead of making statements about the truth of one reconstruction, we would, as structuralists, use it or dispose of it once we no longer deemed it worthwhile. Thus, the theory evolves over time and its success is a matter of historical prevalence rather than objective truth.

What is at stake in the debate between heuristics versus invariants, then, is not empirical truth or falsity but rather the framework provided by each approach to organize knowledge about dynamic event perception. Thus, the approaches can still be evaluated but according to a quite different set of criteria, such as how well derived hypotheses can be described by the language provided by the approach or how easy it is to generate and modify new hypotheses.

The conundrum of incompatible but empirically nonfalsifiable theories is certainly not unique to the two approaches discussed here. Some other positions that could find application in the event-perception domain also come suspiciously close to nonstatements—for instance, inference theory (Rock, 1983), which is based upon the notion that perception has its own logic. A hierarchy of unconscious inferences is postulated that lead to a conclusive percept. However, to date, no attempt has been made to explain the perception of dynamic events in inference theoretic terms. Thus, from an epistemological point of view, researchers in the field of cognitive psychology should be aware of the problems associated with theories that can be understood only as nonstatements. It seems necessary to reevaluate falsification attempts of theories that may not deserve that effort.

CONCLUSION

In conclusion, efforts to directly falsify the theories of KSD or PH cannot have the desired effect and should be modified and turned into tests of specific hypothesis. Researchers who believe that they have found empirical evidence against one or the other approach should reconsider. Researchers who have found evidence in favor of either approach cannot go wrong, but they are well advised to limit their conclusions to the specific hypotheses they tested. Both KSD and PH would not pass as theories from a strictly falsificationist position. It is impossible to empirically distinguish judgments that are based on heuristics from judgments that are based on (incomplete) invariants. The choice of one theory over the other then comes down to personal preferences of language or some other pragmatic considerations.

It appears to be rather fatalistic, though, if one would have to conclude that the adoption or dropping of a theoretical approach was a purely pragmatic decision. I do not second this point of view, and there may be ways to incorporate some of the structuralist ideas within a falsificationist position to remedy its shortcomings. From a neofalsificationist point of view, this was anticipated by Lakatos (1970) even before the structuralist view surfaced: "All scientific research programmes may be characterized by their *hard core*" (p. 133). Lakatos acknowledged that theory cores are often not testable, and suggested that theories should not be evaluated in isolation but only within the context of whole research programs. What is amenable to falsification are auxiliary hypotheses that form a protective belt around the core.

To evaluate a research program, one has to inspect the problem shifts that have occurred in the auxiliary hypotheses. If those have shifted toward more general propositions while becoming simpler or more elegant, the research program is in a progressive shift. If, on the other hand, the auxiliary hypotheses have become more and more specialized, the research program is in a degenerative problem shift and should be abandoned. Thus, Lakatos is able to maintain a largely falsificationist methodology while at the same time acknowledging the factual immunity of theory cores. Falsified hypotheses can be kept in the theory as long as the problem shift is progressive with reference to the fallibility of falsifying observations. Unlike the structuralist position, where the intended applications of a theory can be changed quite arbitrarily, Lakatos's view does not open the door for unconditional life-support for problematic theories.[6]

Thus, one could demand that ideally psychological theories be falsifiable—including their cores. If, in the midst of an ongoing research program, it is not possible to formulate entirely falsifiable theories, we should acknowledge this and come up with an evaluation of the problem shift of the program. Only as a last resort should one consider turning one's theory into an unfalsifiable nonstatement, thus introducing a large degree of arbitrariness. In the case of dynamic event perception, the intensive study of expertise in complex situations could serve as a tool to produce progressive problem shifts in this domain of research.

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NOTES

1. The history of the two contradicting concepts can be retraced in the research that has focused on collision dynamics. Runeson (1975, 1977) originally proposed that observers are able to extract invariants from vector displays of colliding objects. Kaiser and Proffitt (1987) found similarly good performance but only for events in canonical environments with friction. Todd and Warren (1982) found performance suggesting less efficient use of information, and Gilden and Proffitt (1989) provided data from novices in agreement with the use of primitive perceptual heuristics. By using trained observers, different data analyses (Runeson, in press; Runeson & Vedeler, 1993), or different display technologies (Flynn, 1994), ecologists attempted to defend their position, while Gilden and Proffitt (1994) hang on to their model even though, at least in trained observers, performance is better than predicted by simple heuristics (Runeson, 1995).

2. Using physical variables is just one way of categorizing dynamic events, and even though direct perceptionists would certainly prefer to classify events according to other criteria, I find it very helpful in this context.

3. The concept of PH is certainly not limited to collision dynamics (Gilden & Proffitt, 1994, p. 719), and is easily extended to nondynamic events as, for instance, in Caudek and Proffitt (1993), who talk about perceptual heuristics in the context of the stereokinetic effect. This does, of course, not imply that Proffitt and Gilden would necessarily agree with my broad interpretation of PH in the area of event perception.

4. This shortcoming of PH, to remain fuzzy about what aspects of the kinematic information become the basis of a heuristical judgment, has been recognized by Gilden (1991), who offers perceptual segmentation and organization as relevant processes that determine the bases of a heuristic and thus somehow quantify heuristic knowledge.

5. There are a number of criticisms that have been leveled against the circularity problem upon which the structuralist position is founded. For instance, the problem is thought to be a merely theoretical one that does not acknowledge that our observations are usually reliable, and even if observations are based on theories, those are usually not the same as that addressed by the observation in question. See Gadenne (1987) for an extensive discussion of the issue and Kim (1991) for criticism from a perspective of logical positivism.

6. In terms of a progressive problem shift, it is even conceivable that additions to a theory reintroduce falsifiability. For example, one could postulate that a given judgment takes longer processing times when based on a heuristic than when based on its invariant-based counterpart. One would have to add that this difference is measurable in reaction-time experiments to make testable predictions. However, PH and KSD are too broad and not process-oriented enough to easily allow for such desirable additions.

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