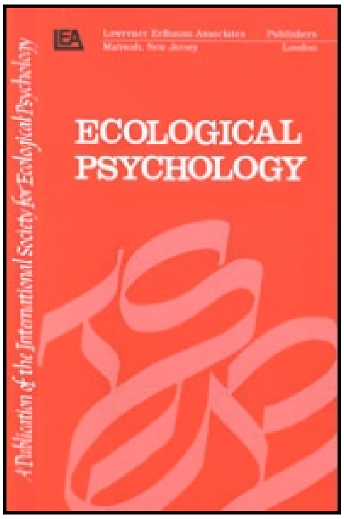

Ecological Psychology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t775653640

Situated Behavior and the Place of Measurement in Psychological Theory

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Online publication date: 29 January 2010

To cite this Article Van Orden, Guy C., Kello, Christopher T. and Holden, John G.(2010) 'Situated Behavior and the Place of Measurement in Psychological Theory', Ecological Psychology, 22: 1, 24 — 43
To link to this Article: DOI: 10.1080/10407410903493145
URL: http://dx.doi.org/10.1080/10407410903493145

Ecological Psychology, 22:24–43, 2010

ISSN: 1040-7413 print/1532-6969 online
DOI: 10.1080/10407410903493145

Situated Behavior and the Place of Measurement in Psychological Theory

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Measured values of human behavior may entail contradictory attributes of wave and particle by analogy with the wave/particle attributes of the electron. 1/f scaling is the wave attribute in this analogy and punctate data points are the particle attribute. One consequence of the wave/particle duality in physics was to elevate measurement to a primary place in physical theory, and one purpose of the present analogy is to likewise elevate measurement to a primary place in psychological theory. Another purpose is to emulate Robert Shaw's creative use of analogies, consistent with the brief quotation that begins this article.

> *Anytime you take a measurement you establish a dynamic linkage between two systems.* (Robert Shaw, personal communication, March 10, 1998)

This quotation by Robert Shaw is one that we have used before and that we continue to try to understand. One usually plays catch-up with Bob Shaw

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instead of catch. The quote concerns how to think about measurement of human behavior—how to think about empirical behavioral science—and the quote is dense with possibility that we partly unpack in this article. The quote also marks a debt to Bob Shaw. He helped us bridge a conceptual gap that, at the time, separated us from ideas like those presented here. His influence came as we had begun to struggle with the question of measurement and human behavior.

Our struggle originates in the historical fact that behavioral science has mostly ignored the dynamic linkage that the quote highlights. So our concerns are in some sense every behavioral scientist's concerns. We all strive to understand what it means to conduct experiments and observe behavior of human participants. In this context, the main issue of measurement has been the precision with which one can measure human behavior. If Bob is right, however, then there are issues of measurement in addition to precision and more fundamental than precision. We illustrate this claim with measurement phenomena that are relatively new to behavioral science.

To unpack the quote, we actually imitate Shaw's use of analogies. In a sense we attempt to *do a Robert Shaw* or *do a Bob* for short. By *doing a Bob*, we mean take phenomena from outside of psychology and use them as guides for our thinking about psychology. Bob is not alone in this practice; he is simply an international master. When he constructs a useful analogy he is cautious, precise, and strategic. He spells out exactly what he intends the analogy to mean and what it does not mean.

In that regard, we expressly *do not* equate physical systems with psychological systems, nor do we derive psychological phenomena from physical phenomena. Instead we juxtapose the phenomenology of each, the patterns or events in the respective system behaviors. We stay close to the surface of the respective phenomena and draw analogies based on how physicists talk about quantum phenomena. With luck, the analogy can re-present or reconstitute the psychological phenomenon from a different and we hope useful point of view (cf. Bechtel & Richardson, 1993).

The *Bob* that we now attempt follows on the quote about measurement and linked systems. In this case the linked systems are a person and a laboratory procedure, a measurement protocol. We hope to justify that it matters, and matters fundamentally, that a *person system* is dynamically linked to a *measurement protocol system* when one takes a measurement. Of course a measurement protocol is a system of artifacts as procedures and apparatus, but it is a system nonetheless constructed for the purpose of abstraction, "an act of replacing the thing being measured ... by a limited set of numbers" (Rosen, 1991, p. 60).

The overtone of our analogy concerns how to treat context in a study of human behavior. Context effects are widely demonstrated. Nonetheless a basic belief persists that the causal basis of behavior is somehow separate from the contexts in which behavior is observed. As scientists, what we profess to know about a system consists of patterns of observations (plus a priori assumptions). Thus, by separate we mean separately expressed in data. Analytic methods that would distinguish context effects from stimulus effects, or brain effects, or mental module effects, for instance, must make the distinction in the data that are collected. The analytic goal is contraindicated, however, if data are ontologically entangled with measurement contexts. If so, then a sufficient account of the data must include a primary role for measurement context. At least that is how things appear in the analogy with physics.

The next section describes an example from quantum mechanics in which the dynamic linkage with measurement protocol can be understood to reveal both wave and particle attributes of electrons. We use the example in an analogy to spell out a parallel "quantum paradox" in human performance. After that we describe experiments that amplify this paradox. The lesson about measurement concerns what kind of system we take measurements on. The component systems of a human being are dynamically coupled and that dynamic linkage, in turn, implies a dynamic linkage between human beings and their environments—including the laboratory environments defined by measurement protocols. The consequences elevate measurement to a primary place in psychological theory.

THE WAVE/PARTICLE DUALITY OF AN ELECTRON

Few results in science attract the interest and even mystical cachet of quantum phenomena. The example we use is the wave/particle duality of the electron. What interests us is that individual measurements of human performance also show a kind of wave pattern across a participant's successively measured data points. Data points across separate measurement trials accumulate in a fractal wave pattern—a duality of sorts. To introduce this way of seeing human data we need to spell out more detail of the behavior of electrons. We describe what it is like to exhibit characteristics of both wave and particle.

Nick Herbert (1985) illustrates the wave/particle coexistence using an electron gun and the phosphorous screen of a conventional television. In Herbert's illustration, the electron gun is aimed at the phosphorous screen through a tiny iris and tuned to emit one electron every second or so. Each electron fired from the gun passes through the iris and strikes the phosphorous screen. A strike emits a photon from the point of the screen that was struck. Observation consists of noting where on the screen each photon is emitted and the pattern of emissions that builds up over time. Imagine that each emission leaves a permanent mark on your TV screen, every second or so, each time an electron strikes.

Each electron is shot through the tiny iris, which can contract or expand its opening like the iris diaphragm of an eye. Shrinking the tiny iris to a critical-size opening creates a wave pattern in the accumulating strike points, concentric rings surrounding a bulls-eye. Remarkably, each electron appears guided to play its part in the accumulating pattern as it comes into existence one electron strike per second. But no unseen hand is at work. Nevertheless, the eventual globally patterned outcome implies that each electron strike is connected across time to every other electron strike.

Wave/particle duality created a paradox for the classical view of matter. The paradox lies in the simultaneous presence of properties of distinct physical existences. "As a particle, [an electron] must be localized in space, cannot be split apart, and retains its identity in collisions with other particles. As a wave, it spreads over vast regions of space, is divisible in an infinity of ways, and merges completely with other waves it happens to meet" (Herbert, 1985, pp. 63–64).

To resolve the paradox a physicist accepts a dynamic linkage between the measured electron and the measurement protocol. "Because measured electron is radically different from unmeasured electron, it appears that we cannot describe the [electron] without referring to the act of the observation" (Herbert, 1985, p. 66). Compare that statement with this one: "There can be no absolute physical conception of nature but only a total ecology for physics that includes the physicist as both perceiver and actor in the experiments run and the observations made" (Shaw & Turvey, 1981, p. 414).

The dynamic linkage between electron and protocol raises the act of observation to a more prominent position in the explanation but not in some mystical sense. Macroworld measurement protocols are dynamically linked to the quantum microworld, and it is via this linkage that a qualitative change is induced when the microworld is observed. Wave and particle dualities emerge because the connection allows measurement procedures to induce qualitative change (Abe, 2004; Laughlin, 2005). Quantum phenomena are, strictly speaking, products of the dynamic linkage between quantum microworlds and the quasi-classical macroworld in which measurement events occur (Gell-Mann, 1994). This was the difficult pill to swallow historically. Measurement outcomes differ in quality from the quantum microworld that is measured.

In the next section we discuss evidence in human behavior that parallels the duality of wave and particle. We suggest also that qualitative change is induced when human behavior is measured. We draw out the analogy between the punctate character of electrons and punctate individual data points in a behavioral experiment. A wave pattern of variation across behavioral data takes the role of the wave pattern of variation in electron strikes. These together comprise a kind of wave/particle duality in human performance. This also appears paradoxical if one relies on conventional ideas. But first we finish this discussion of challenges that the quantum reality created for classical physics.

The quantum paradoxes implied that classical thinking lacked some essential ideas (Laughlin, 2005). For instance, measurement had played a secondary role in classical physics, the primary issues being objectivity and precision, how reliably precisely a phenomenon could be measured. This is not to say that quantum phenomena are not objective or are unreliable; they do not depend in some essential way upon a conscious observer, for instance. Quantum phenomena emerge all the time in interactions between quantum stuff and "the rest of the universe" (Gell-Mann, 1994, p. 153). Quantum phenomena themselves are as rock solidly objective as other physical phenomena and they are reliably produced to satisfy the same statistical descriptions over and over again. However, the attributes of quantum phenomena do not exist independently of the measurement protocol.

Wave or particle attributes depend on reliably reproducing specific contexts of measurement. As a consequence, the wave/particle outcomes cannot be separated from these contexts. Another way to say this is that the phenomenal attribute is situated or embedded in its context of measurement or that the context of measurement is constitutive of the phenomenon. Contexts are constitutive of phenomenal attributes to the extent that attributes depend on the interaction with context. In the example of electrons, phenomenal attributes are ontologically entangled with their measurement contexts. They come into and out of existence with the measurement context. Wave and particle do not exist separate from contexts, whereas classical phenomena were imagined to be context free.

Quantum dualities are emergent. The term *emergent* refers to phenomena that depend for their existence on a dynamic linkage among system components or equivalently component systems. Emergent phenomena exist only as products of the dynamic linkage. They are exclusively dynamical phenomena. They don't have a separate off-line existence in the separate components of a system, only in the dynamic linkage among components or systems. Consequently, though a quantum reality may exist separate from measurement protocols, the measurement phenomena do not; they are emergent (Laughlin, 2005). In the strongest sense of emergence, the phenomena in question cannot be predicted even in principle from the independent behaviors of component systems (Boogerd, Bruggeman, Richardson, Stephan, & Westerhoff, 2005).

Emergent phenomena are also collective phenomena. The term *collective* refers to phenomena that depend for existence upon the mutually reinforcing contexts that a collective of component systems creates for one another. The linked collective of quantum stuff and measurement protocol in the example yields the measured attributes as collective phenomena. The attributes themselves have no basis in reality apart from how they appear in the measurement event. Thus electron wave or particle cannot be taken apart into anything smaller. There is no more basic reality than the observed wave and particle products of the measurement protocol.

THE WAVE ASPECT OF HUMAN PERFORMANCE

In this and the next section we spell out the analogy between electrons and punctate individual data points in behavioral experiments. Individual data points plus a wave pattern of variation across behavioral data comprise the wave/datum duality in human performance, which creates a challenge for classical psychology. The challenge that psychology faces parallels the challenge that quantum reality created for classical physics.

The wave phenomena that motivate the analogy come from widely observed fractal waves, which we see in scaling relations of repeated measurements of human behavior. The same kinds of scaling relations appear widely in many kinds of human performance and are reinforced by converging observations of the systems of which humans are composed (for reviews see Gilden, 2001; Kello & Van Orden, 2009; Riley & Turvey, 2002; Van Orden, Holden, & Turvey, 2003). Scaling relations have also been observed in many other areas of science. Geography presents a well-known example in the length of a jagged coastline. The measured length of a jagged coastline depends on whether it is measured in 100, 10, or single kilometer units. Each shorter "ruler" or scale will yield a different, significantly longer coastline—there is no particular characteristic length to a jagged coastline.

The length of the jagged or wavy coastline depends upon the units in which it is measured; it has no preferred scale. The wavy coastline has length-adding features at many scales, from large and small inlets and bays to rock faces of all sizes, each composed of many nested juts and jags. Consequently, the smaller the ruler the better access to smaller length-adding features. Nonetheless, as a natural fractal, there is a reliable inverse relation between how big a ruler is used, the size of measured changes, $S(f)$, and the frequency of changes at that size (f), which equals a measured length of the coastline at that scale. The differently measured lengths of the coastline (f) will, altogether, be inversely proportional to the unit scales of measurements $S(f)$ on log/log axes. This proportional relation is a scaling relation and demonstrates that the coastline has fractal structure.

The scaling relation in human performance also captures a jagged wavy pattern in the variation across repeated measurements. The measurements are of a person performing repeatedly a task, treating the trial-series of repeated measurements as a time series. Two quantities describe the wavy changes from one measured value to the next across the time series of repeated measurements: how big the change is and how often, or with what frequency, such changes occur. In repeated measures of human performance the size of changes, $S(f)$, is inversely proportional with how often changes of that size occur (f) on log/log axes, another scaling relation suggestive of fractal structure.

The scaling relation is called $1/f$ *scaling* or *fractal time* and many other names depending on the discipline in which it was observed. The wave aspect of human performance is an irregular, aperiodic waveform. Analysis of the waveform, however, reveals a statistical kind of self-similarity in which the outcome resembles nested changes at an indefinite number of frequencies or "wavelengths" all proportional to their amplitude of change (Gilden, 2001; Riley & Turvey, 2002; Van Orden et al., 2003). Each repeated measurement of behavior finds its place in this proportional relation, as though some unseen hand had stitched together the string of repeated measures, but no hand was present.

For example, $1/f$ scaling is observed across repeated measures of simple reaction times. Each reaction time is the time that passes from a signal to act until an action that stops the clock. The signal can appear on a computer screen or be heard via headphones, and the action can be a key press, a spoken sound that trips a voice key, a foot slam on a brake pedal, or some other act to stop the clock. The measurement protocol consists of many, many repeated trials presenting identical signals to which repeated reaction times are taken. The fractal pattern is found in the variation of measured reaction times, one trial to the next across scores, hundreds, thousands of measurement trials.

This aperiodic waveform can be broken down artificially into multiple component waves, usually sine waves. The analysis segregates component waves yielding rapid, higher frequency oscillations plus intermediate frequency oscillations plus low frequency oscillations. The scaling relation dictates the relation between amplitudes and frequencies, and the remarkable finding is that amplitudes are related linearly on log scales to frequencies illustrated in Figure 1. The amplitude of oscillation across blocks of hundreds or thousands of trials finds its value on the same line that captures amplitudes for oscillations with periods of tens, dozens, or scores of trials.

THE FRACTAL WAVE/DATUM DUALITY

In the analogy with quantum behavior, human behavior appears as a discrete datum in the immediate context of measurement but exhibits a contradictory fractal wave attribute over the larger context of the experiment. We see the contradictory attribute in the global pattern that appears across the measurements, and all the measurements are part of the shared pattern. Thus in the wave attribute each measured value of reaction time is in some sense connected through time to every other measured value in the fractal wavelike unity (Treffner & Kelso, 1999).

The parallels here justify reexamining the place of measurement in psychological theory. The *act of observation* or measurement has played a secondary role in classical and conventional behavioral science. By secondary we do not mean unimportant. For example, recent decades have included rigorous evaluation of measurement assumptions in behavioral science. Elegant work in

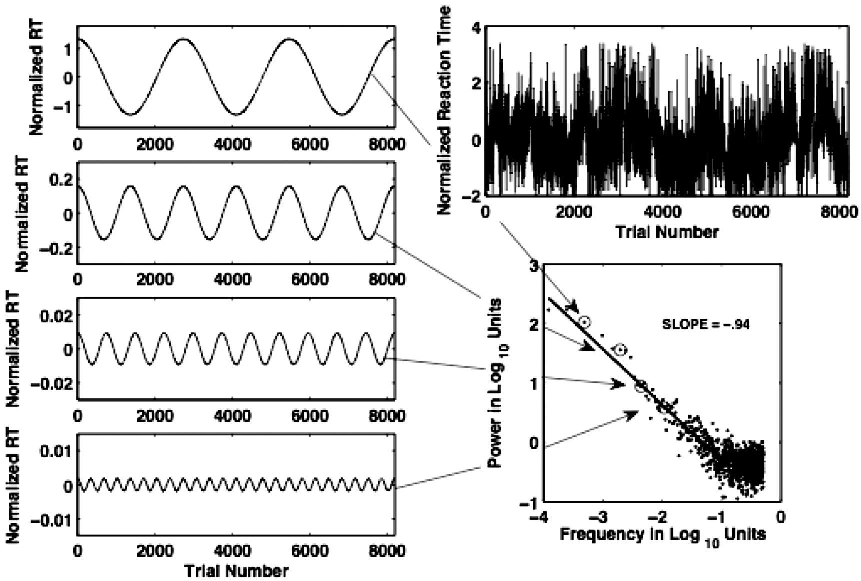

FIGURE 1 Typical protocols revealing $1/f$ scaling consist of many repeated measurement trials. $1/f$ scaling appears as a complex waveform of variation across the series of measured values. For example, the graph of connected points (upper right) includes 8,192 normalized simple reaction times, graphed in the trial order in which they were collected. It presents variation across simple reaction times as a rough waveform. X-axis portrays the trial number, and Y-axis is reaction time (RT) in normalized units. A spectral analysis (lower right) parses the rough natural waveform into an artificial set of ideal sine waves (left) very much as a prism decomposes white light into elemental frequencies. Four sine-wave plots illustrate the sine wave frequencies depicted as points in the spectral plot. The uppermost sine wave is one of the three lowest frequencies necessary to approximate the graph of simple reaction times. Y-axes were enlarged to make the small waves visible. The arrow that extends from each sine-wave plot to its representation in the spectral plot indicates a specific circled point, representing the frequency and magnitude of the particular wave. X-axis of the spectral plot is (log) frequency and Y-axis is (log) power or magnitude. Most important, frequency and power are proportionally related on log scales—this is the scaling relation. In the power spectrum the scaling relation appears as a line with negative slope. The scaling relation is called $1/f$ scaling because power (p) is the inverse of frequency, and frequency is the f in the $p = 1/f$ nomenclature. If all the sine waves portrayed as points in the spectral plot (with the appropriate phase) were added together, the outcome would approximate the upper right, trial-ordered graph of the reaction times.

mathematical psychology has reasserted and elaborated the essential connection between measurement scales and additivity, or *concatenation* of effects, which is necessary for reliable characteristic scales of measurement (summarized in Luce, Krantz, Suppes, & Tversky, 1990).

This important work did not have the larger impact in behavioral science that it probably should have (Michell, 1999), but it clearly shows how important measurement issues are, even in a secondary role. Widespread $1/f$ scaling, however, obviates the concerns of this earlier work. Behavior is scale free. We lack the kind of rulers that measure amounts of human behavior, such as the amount of time required for a behavior. Different ideas about measuring must be considered, including, for instance, that measurements change behavior.

Psychologists have long known that participants' behavior can change on the simple fact that participants are aware that they are being observed. Participants will purposefully comply or not comply with their often mistaken understanding of what an experimenter wants, for example (as when a participant figures out an experimenter's game). These kinds of facts fill a mixed bag of phenomena lumped together as so-called Hawthorne effects (Wickstrom & Bendix, 2000).

Compared with $1/f$ scaling, however, Hawthorne effects have not yet created general problems for measurement. The sole issue at stake has been the secondary issue of measurement precision. Hawthorne effects are treated mostly as *confounds* of true and precise measurement, as mere obstacles, sometimes surmountable and sometimes not, to precise measurement of the true effects under study.

The fractal wave/datum duality greatly outstrips conceptually what was thought to be worrisome about Hawthorne effects. The duality is sufficiently paradoxical to discombobulate observation's conventional secondary role, just like what happened in physics. From a classical viewpoint, phenomena of human performance are ideally context free and independent of context of measurement (Cronbach & Meehl, 1955). One's goal is to isolate causal relations free of context just like the goal of classical physics (Borsboom, 2005). The wave/datum duality is paradoxical for this goal.

As with the quantum duality, the prominent context-free phenomenon is the duality itself, which precludes the separation of context and phenomenon. The paradox cannot be surmounted by more careful experimental design and more precise measurement. In fact, all other things equal, the more carefully and precisely one takes the repeated measurements, the better one controls and minimizes external sources of perturbation, the more clearly apparent the fractal-wave/datum duality (Kello, Beltz, Holden, & Van Orden, 2007).

Sufficient care and precision in repeated measurements is kind of like finding the critical diameter of the tiny iris that clarifies the wave pattern of electrons. Thus our best efforts simply reinforce the paradox. As a single datum a behavior is localized in time. The measured act retains a singular identity at the particular moment of measurement on the particular day of measurement. As such it is indivisible, it cannot be analyzed further, it cannot be split apart.

Yet as a fractal wave the intuitive distinction between measurement trials is blurred. The same behavior spans seconds, minutes, and hours and in other examples days and months (Delignières, Fortes, & Ninot, 2004; Gottschalk, Bauer, & Whybrow, 1995). As a fractal wave, behavior is infinitely divisible and merges completely with concurrent activities, out to the temporal limits of the measurement protocol. Despite the compelling intuition that a simple-reaction-time datum, far back in the past, should be pretty much independent of a simple-reaction-time datum in the present, past and present are enfolded in a fractal unity across the hierarchy of timescales that an experiment spans (cf. Flach, Dekker, & Stappers, 2008).

In the analogy with quantum dualities, these contradictory aspects of human performance cannot be accommodated without referring to the act of the observation. It is the dynamic linkage of person and measurement protocol that yields two contradictory attributes in human performance: punctate datum and fractal wave. No amount of conniving can break this linkage to reveal a more basic psychological reality (Kugler, 2007). At least that's how it seems in the analogy with quantum reality.

Continuing in the analogy, it appears that important ideas are missing in the classical viewpoint. One missing idea is that human performances are emergent phenomena (Kugler, 2007; Van Orden et al., 2003; Van Orden, Holden, & Turvey, 2005). The component systems that compose a measurement, including the component systems of brain, body, history, and protocol—the task ecology—yield emergent change when human behavior is measured. Prior to a simple reaction response, the potential exists for an indefinite number of response trajectories (Bernstein, 1967). Measurement trials collapse the potential for many behavioral trajectories to become the unique trajectory of the actual response that is observed (Pattee, 1992; Rączaszek-Leonardi & Kelso, 2008; Van Orden, Kloos, & Wallot, 2009; Wheeler, 1998), consistent with statistical descriptions of human performance (and statistical descriptions of quantum phenomena).

In the analogy with quantum phenomena, each observation of human behavior is a unique product of the dynamic linkage between participant and measurement protocol (Flach et al., 2008). The performance attributes do not exist separately from the measurement protocol or from the entangled interaction of body and brain with circumstances of history, and it is not possible to parse data variation into underlying protocol mechanics or a history mechanism (cf. Rosen, 1991).

One cannot isolate the present protocol from past circumstances in a datum. Each datum is contextually and historically situated. Measurement outcomes are nevertheless objective and reliably produced to satisfy their statistical descriptions over and over again—just as they are for quantum outcomes. These reliable demonstrations depend, however, upon reliably reproducing specific contexts of measurement so human performances are not separable from these contexts—again like quantum outcomes.

Behavioral phenomena are situated in their task ecology, which means they are causally embedded in their task ecology. The term *ecology* serves to better communicate that context is always defined relative to an actor (Flach et al., 2008). Phenomenal attributes of human behavior are radically dependent on their ecology; they depend for their existence on the presence of specific contexts. Phenomenal aspects of human behavior do not have the context-free ontology that classic behavioral science has assumed.

Context dependence is consistent with the idea that behavioral dualities of fractal wave and datum are emergent. They depend for their existence on the dynamic linkage among component systems, including measurement protocol. They are exclusively soft-assembled dynamical phenomena, which is a term meaning they don't have a separate, hard-assembled, off-line existence in physiological or physical components, and they cannot be predicted from the individual behaviors of such components. Human behavior originates in temporary dynamical mechanisms of participant-history-context systems.

AMPLIFYING THE PARADOX

The fractal wave patterns of $1/f$ scaling are found widely in science. In each discipline the initial response has been a reluctance to believe that the pattern is an actual fractal. It remains possible in practice to mimic a fractal pattern ad hoc, using precisely chosen mechanisms (e.g., Wagenmakers, Farrell, & Ratcliff, 2004). Yet these attempts lead quickly to absurd conclusions. Benoit Mandelbrot explained why in the 1960s (Mandelbrot & Wallis, 2002). Ad hoc models are tied too closely to the surface details of particular data sets, such as the specific size of a collected sample.

Conventionally, collecting more data gives more reliable estimates of population statistics in sample statistics, and that is all. In fractal data, however, a longer data set reveals new scales of fractal structure not present in the shorter sample. Longer data series reveal new and larger amplitude variations across trial blocks of greater length, for example, extending the fractal pattern outside the range of the previous sample. Thus a standard ad hoc model must reconstitute its sources of variation every time a longer data set is collected. One need only collect more data to "falsify" the model.

More cognitive components will be required for the same person's trial-series from the same cognitive task differing only in more time on task (Thornton & Gilden, 2005). For example, suppose that we could take 10,000 or 100,000 trial observations in one continuous well-conducted experiment. If a scaling relation exists, then one discovers variation of greater and greater amplitude in the longer and longest data series. More data expand the phenomenological unity across a wider swath of time (Van Orden et al., 2005). Thus a standard model must add more and more long-range memory components each time a longer data set is collected. This is technically possible although what plausible theoretical motivation exists for such a fix?

Another fix for conventional models would be to encapsulate $1/f$ scaling in a particular component system and treat it as an add-on feature of a system's behavior, possibly interesting and important but not necessarily so (Delignières, Torre, & Lemoine, 2008; Wagenmakers, Farrell, & Ratcliff, 2005; cf. Bills, 1943). However, again the ad hoc solution is tied too closely to the surface details of data, such as the particular kind of measured value that is being collected. One need only collect additional kinds of measured values to falsify the model.

Interleaved measurements of a repeated behavior reveal interleaved streams of $1/f$ scaling. Thus the standard model must add more and more long-range memory components each time another aspect of a behavior is measured. For example, take two measurements of a key press response. In addition to reaction time between stimulus and key press, record *key contact duration*, which is how long a key is held down. Both measurements come from the same key press of the same trial and the same participant and can be repeated, trial after trial, and they will both express the common grammar of $1/f$ scaling or fractal time (Kello et al., 2007).

These individual fractal patterns will be largely uncorrelated. Thus, if one's goal were to dissociate separate mechanisms of body and mind—in the sense of separate mental modules or brain components or whatever—each measurement would appear to require its own separate module or component. The standard model must add more and more long-range memory components each time another aspect of a behavior is measured and thereby dissociated.

The paradox is further confirmed in an ordinary logic of dissociation, now applied to two streaming fractal patterns in the key press response. Each of the two measured aspects of the key press response yields the same kind of fractal pattern, but perturbations to the reaction time protocol (introduced uncertainty about which key to press on each trial) change the fractal pattern of the reaction times while having no effect on key contact durations (Kello et al., 2007). This manipulation of uncertainty about which key to press dissociates key-pressing behavior expressed as a reaction time from key-releasing behavior expressed as a key-contact duration.

The dissociation might be all right if the complexity ended there, with two measurements and two kinds of behavior. But it's trivial to up the ante on the number of measurements that reveal uncorrelated fractal structure, another basis for dissociation. One can take indefinite numbers of measurements from an acoustic pattern of speech, for instance. If the same spoken speech is repeated many, many times each measurement will yield a time series with its own fractal pattern, uncorrelated with the fractal patterns of the other repeated measurements (Kello, Anderson, Holden, & Van Orden, 2008).

Yet, if arbitrarily chosen measurement series have independent status, then they infuse arbitrary behaviors with distinct origins, and the standard model must rapidly accumulate an indefinite number of arbitrary and meaningless long-range memory components. These increasingly absurd conclusions, however, all come from thinking that independent sources of variation in measurements of behavior can be equated with components of cognition—that variations in measured values are transparent to state variables of distinct functionally specified components (cf. Rosen, 1991).

The absurdity descends from the idea that variation in measured values originates in independent component sources and is therefore transparent to causal properties of component sources. One can move past the absurdity, however, by recognizing that measured values are exclusively emergent products of dynamically linked component systems, including the system of the measurement protocol, as Robert Shaw reminds us in the quotation that opens this article.

MOVING PAST THE PARADOX

The utmost concern of this article is a better understanding of the mechanisms of behavior and how measurements speak to these. If task ecology of measurement fundamentally determines measurement outcomes, then it must figure fundamentally in the origins and explanations of behavior. Our exclusive scientific access to mind-body interactions is via measurements, which reveal emergent and contradictory attributes in a wave/datum duality. The analogy with quantum duality simply makes the dynamic linkage of participant and measurement protocol more intuitive.

The dynamic linkage looms large in both the quantum case and the human case of wave/datum duality. Also in both cases the protocol is linked dynamically to a system well below the surface of what is directly observed. In the quantum case, below the surface refers to the quantum microworld. In the human case, below the surface refers to the microworld of mind-body interactions. In both cases, we infer the presence of collective activity and emergence from patterns and paradoxes of measurement outcomes.

These observations all confirm a common principle. The principle concerns the origins of dynamic mechanisms in behavior, not the mechanics of behaviors themselves. It refers to how mechanisms are constructed and enacted in behaviors. This principle is *interaction-dominant dynamics*. Emergence entails interaction-dominant dynamics, as demonstrated in a significant analysis of the sandpile/ricepile models of self-organized criticality (Jensen, 1998). Interactions among component systems change each other's dynamics in the interaction. Components that change each other's dynamics can create new mechanisms in their collective configuration.

Interaction-dominant dynamics concerns the dynamic linkage among system components. The dynamic linkage between participant and measurement protocol yields measurement phenomena. If we marry these two ideas, they explain why human performance equals emergent performance. Once again, as in the quantum paradox, the difficult concept is context sensitivity. Classical science assumed context-free phenomena in the sense that one could always partition out the effect of context. However, a participant comprises dynamically linked component systems that change each other as they interact to become the device that an experimenter requests (Kugler & Turvey, 1987; Turvey & Carello, 1995). The context of the measurement protocol constrains and situates the interaction of component systems. Thus it becomes possible to construct a limitless variety of mechanisms, a possibility that originates in the dynamical physiology of participants themselves (Van Orden et al., 2009).

Continually updating, interaction-dominant dynamics inculcate changing relations to context as sources of constraint on embodied dynamics, head to toe. Consequently context is perpetually constitutive of behavior. This idea is attractive. It implies that not only human performances (as measured values) are emergent but also the functional character of human behavior (Kloos & Van Orden, 2009). It allows context to be constitutive of cognition and behavior (Hutchins, 1995; Juarrero, 1999; Shanon, 1993), and it takes into account changing relations to context in the bargain. The flow of relations, from the perspective of the participant, enters the embodied interaction as a flow of active constraints and permeates the embodied interaction because the dynamics of the brain and body are interaction dominant (Hollis, Kloos, & Van Orden, 2009).

In other words, context is not simply a backdrop to action or a stage on which action occurs. Context is coauthor of the play, sharing copyright with its actors (Flach et al., 2008). The entangled coauthorship allows the participant's understanding of laboratory instructions, for example, to sufficiently constrain the interaction of brain and body such that the participant becomes the requested laboratory device—a remembering device or a simple-reaction-time device or something else. The device itself does not exist off-line, however. It is a temporary product of temporary configurations of body and mind situated in intentional contents to suit the laboratory ecology in which they must behave. Only temporary devices can flexibly situate a person in the flow of oncoming contextual change.

Because task contexts are constitutive of task performances we continue to discover endlessly contradictory parades of cognitive components, many no more profound than key-pressing and key-releasing devices. The embodiment of task participation constructs subdevices for an indefinite number of subtasks, specific to the context of measurement, many or all of which can be dissociated in measured behavior. After all, the measurement protocol is constitutive of the measured behavior. For instance, the trivial dissociation of key-pressing and key-releasing behaviors reflects the dynamical coupling between participant and task, exclusively. Uncertainty about which key to press is a source of unsystematic variation from trial to trial, which will make the pattern of variation across trials appear more random in the trial-series of response times. Once a key has been pressed, however, no uncertainty exists about which key to release, so the pattern of variation across trial-series of key-contact durations is unaffected (Van Orden et al., 2009).

Thus the dissociation originates exclusively in dynamical relations between participant and task, specific to key pressing. Reliable dissociations, as reliable qualitative differences, do not pick out different structural components. They pick out different configurations of the same components. It is the dynamical configuration of task, brain, and body that presses or releases a response key or remembers a previously studied melody, and the functional character of performance refers irreducibly to such temporary contextually situated configurations.

IN RETROSPECT

"The poet Donne observed that no man is an island; neither is any given natural system on which we focus scientific inquiry, for it is afloat in a cosmic sea of constraint" (Shaw & Turvey, 1981, p. 376). Compare again with quantum reality as we paraphrase Herbert (1985): Because measured performance is radically different from unmeasured performance, it appears that we cannot explain observed performance without referring to the context of the observation. Human performance is situated performance because the capacity to situate behavior is the fundamental competence of living systems.

In light of the previous claim we may reexamine historical trends in cognitive science. Hubert Dreyfus (1992) famously summarized four implicit assumptions that persist in contemporary cognitive science: (a) the *biological assumption* that brain mechanisms are at some level discrete operations, akin to binary switches; (b) the *psychological assumption* that mind mechanisms are formal rules to operate on discrete packets of information; and these assumptions rest on (c) the *epistemological assumption* that all knowledge can be equated with formal, logical rules and relations, which in turn requires (d) the *ontological assumption* that everything expressed in human activity can be analyzed with respect to logically and contextually independent facts.

What Dreyfus (1992) and others have demonstrated, however, is the ringing absence of support for any of these assumptions in naturalistic, real world, human activity. Domain experts, such as firefighters, tank commanders, and nurses do not make decisions by following rational operations and formal option-weighing techniques. They perceive and act to satisfy fluid constraints of embedding contexts and unfolding situations (Klein, 1998; Vicente, 1999). Likewise, situated face-to-face communication succeeds because participants are dynamically linked to fluid changes in the local shared context (Shockley, Santana, & Fowler, 2003; Suchman, 1987). To account for situated human activity, an emphasis on logical and symbolic operations quickly enters an infinite regress of rules, about using rules, emerge to accommodate the endlessly accumulating context-specific exceptions (Dreyfus, 1992).

At the beginning of cognitive science, the most studied human performances appeared to entail logical operations on the discrete products of passive perceptual processes—what we might now loosely refer to as *the particle perspective*. Situated *wavelike perspectives*, on the other hand, highlighted interaction, interdependence, and continuity across time. Subsequent debates that would have settled the matter, one way or the other, led instead to stalemate or paradox. However, cognition itself is not paradoxical; nature only appears paradoxical through misunderstanding. Paradox arises in the way theoretical questions are framed, not from inherent contradictions in the object of study.

Performance phenomena are neither "particle" nor "wave"' exclusive of the other; nor do particle and wave aspects refer to different origins. The two aspects of performance both refer to temporary, contextually situated configurations of brain and body. Each token of measured behavior is ontologically situated in its immediate and historical context (Shaw & Turvey, 1999). Context is constitutive of human performance, which brings to the foreground empirical relations between contexts and participants—*measurements* no less. If so, then it will be in participants' relations to contexts that we will discover dynamical mechanisms of behavior (e.g., Shaw, Kadar, Sim, & Repperger, 1992; Shaw & Kinsella-Shaw, 1988; Shaw, Kugler, & Kinsella-Shaw, 1990).

CONCLUSIONS

We have tried to understand consequences of the fact that measurement entails a dynamic linkage between systems both as an issue of measurement and of the nature of living beings. Among our conclusions was that scientific psychology is not about functionally specified components of body and mind. Measurements are not transparent to state variables of functionally specified component processes. The emergent nature of measured values explains why. Situated behavior refers to the situated interaction among components but does not reduce further. By analogy, nowadays, a quantum physicist would not likely seek to isolate the wave aspect of the electron in one physical process and the particle aspect in another. That would not make good sense of quantum phenomena.

Like the quantum dualities, the fractal-wave/datum duality of behavior tells us something fundamental about the system doing the behaving. We are thus forced to adjust what it is that behavioral science is about. We must clarify and refine the new ideas that can accommodate features of complexity. Among these ideas are *interaction-dominant dynamics, emergence, contextually constituted behavior,* terms that draw meaning within the more inclusive metaphors of complexity science.

Our conceptual framework also needs to accord measurement a primary place in psychological theory. As students of behavior we confront emergent properties and we require research strategies inclusive of emergence. Also, as we have tried to illustrate, our conceptual toolbox may include formal and informal analogies to reconstitute psychological phenomena. The immediate promise is that lessons learned in one discipline may inform working hypotheses in another. The Shaw citations that pepper this article are returns on that promise in spades, and one way forward is to emulate Robert Shaw's productive use of analogies.

ACKNOWLEDGMENTS

We wrote this article to honor and celebrate the career of Bob Shaw and his influence on our thinking. These aims originated in a like-minded conference titled *Symmetry and Duality: Principles for an Ecological Psychology* held at the University of Connecticut in June 2004 (see Carello & Turvey, 2005; Carello & Wagman, 2006).

We acknowledge support from the National Science Foundation, including DHB 0728743 to Guy Van Orden, BCS 0239595 to Christopher Kello, BCS 0446813 to John Holden, and BCS 0642716 to Guy Van Orden and John Holden.

We are indebted to Heidi Kloos, Mike Riley, Matt Streit, and Anna Wallot for written comments on manuscript versions of this article and late-night pubtutorials by Peter Kugler concerning measurement and perception.

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