ON THE VALUE OF CONSTANCY, THE CONSTANCY OF VALUES, AND THE SINGULAR ROLE OF TIME IN FUNDAMENTAL PSYCHOPHYSICAL LAWS

Hans-Georg Geissler
University of Leipzig, hans-g.geissler@rz.uni-leipzig.de

Abstract

Newton's Law of Inertia was a slap in the face of intuitions on mechanical motion on earth; fundamental physical laws just are not generalizations across observable phenomena. Like the physical prototype, fundamental psychophysical laws are hypothetico-deductive by nature, i.e. translate into observable trajectories for contingent physical constraints and task demands. They thus cannot be pinpointed behaviorally by strategies following the ruling empiricist ideology; nor can they physiologically. Rather, it is psychophysical constructs that enable identification of parameterized physiological correlates (Fechner's "Functional Principle"). It will be shown that well-known regularities are derivable from behaviorally-founded hypotheses about cyclic carriers, including two constants: self-similar ordering anchored on a base-level cycle; limited temporal coherence after entrainment; capability of hierarchical phase coupling; undisturbed superposition; random selection-by-inhibition imposed by external constraints. Most strikingly, EEG bands are correctly predicted in absolute terms and both predicted quantal-range extensions and growth of dispersions turn out to be construct-based versions of empirical relations as advanced by Teghtsoonian.

"Psychophysics would have kept pace with physics all the time were it not for the so much bigger difficulties that it is faced with" (Fechner, 1860).

It was a dream of early Psychophysics that one day simple, elegant regularities would be shown to link every aspect of mind stuff comparable with the way in which Newton's laws were presumed to explain all forms of motion in the universe. The second volume of the "Elements of Psychophysics" breathes the flair and vigor of this vision. How serious Fechner was in believing that all psychology in essence reduces to psychophysics and to applications of its basic principles is testified by his amazement about Wundt's plan to establish a Psychological Institute in Leipzig, which he commented saying "Then all psychology will for you be done with within a couple of years" (Wundt, 1921).

Certainly, Fechner's bold prophecy of psychology dissolving into a deductively operating psychophysics was doomed to fail. Psychology *had* to go the path of inductive empirical differentiation that it actually went along. Does this, however, imply that the project of a unifying theory encompassing a wide range of psychological phenomena had been unfounded altogether? I don't think so. In this paper, I am going to lay open quite the contrary, namely that, in a precisely circumscribed sense, a theory reverting to fundamental laws is still a waiting goal of critical importance for the future development of psychological science. Rather than joining debates that touch the issue on a general conceptual level I shall put forward a constructive specimen of an enterprise allowing derivation of testable consequences and thus putting discussion on a tangible basis. This germ of a deductive theory, as incomplete and even embryonic as it may be, enables the identification of deep-rooted regularities in seemingly irregular surface structures that cannot be disentangled by common strategies of modeling. Thus there appears to be a good prospect of expansions that may develop into a permanent aid furnishing paradigm-centered research with new instruments of analysis and hypothesis formation.

What about Fechner here? Will he still have a say in this matter? Let us see.

Prerequisites in approaching the issue

“Fundamental Laws”

Even for an approach moving forward straight ahead as promised, some preparatory work is unavoidable. To begin with, it is recommended to call to mind what the term “fundamental law”, borrowed for psychological purposes from physics, implies. When using the word “law” in psychology, we commonly refer to the analytical description of a reproducible empirical relation as obtained by (“concentric”) generalization across *closely interrelated phenomena* and associated stimulus conditions and task demands. Let us call this an empirical law. Empirical laws contain free parameters allowed to vary across special cases involved. As a typical example think of the modality-specific exponents in Steven’s Power Law as obtained with standard procedures. Fundamental laws—in the following exemplified by the dynamic laws of classical or quantum mechanics—are of a different nature: *First*, the parameters they contain are universal constants of nature. *Second*, they are not established by generalization across nested sets of adjacent conditions. Quite the reverse, Newton’s Law of Inertia, for example, was a slap in the face of intuition on mechanical motion on earth telling us that bodies put into motion will sooner or later stop moving. In this vein, the strongest reason for confidence in the dynamic laws in physics is that they (a) *apply invariantly* to and thus (b) link together *most disparate phenomena* and the pertaining conditions, say, for instance, a black hole hidden in the depth of space and the exchange of particles taking place in our own bodies. These differences to the common psychological meaning root in a deeper conceptual disparity: In contrast to an empirical law which relates to its special applications through values of its parameters, there are two, conceptually strictly separated, steps involved in the relationship between law and predictions deriving from it: First, the determinants characterizing a given situation enter into a fundamental law in the form of initial and other side conditions, on this way revealing a specified representation of it. This also holds true of laws applying in combination. For instance, the laws of inertia and gravity in conjunction may get specialized by the masses of planets and the sun and the corresponding initial positions and velocity vectors. Second, from descriptions thus specified derive predictions, in the example: orbits of planet and sun motion. Generally, predictions for particular conditions are those admissible trajectories that are *consistent* with the implementation specified for these conditions. What is important for our purposes, we can rely upon this definition regardless of technical issues that may be involved in pinpointing effective “solutions”.

A paradigm to start with

At first glance it may appear bizarre to suppose that the small world of our brain operates by laws of its own legislation in quite the same way as the world as a whole on the basis of natural laws. Doesn’t such a claim contradict all that we know about the brain *and* about the world? Not to worry, such scruples go astray. Differences remain as large as they are. All that is involved is the possibility that the brain in its phylogenesis evolved an organization in the time domain anchored in principles of functioning that are holistic in the sense that they hold in permanence, from the level of local processing throughout up to the level of cooperation among modular global constituents. That an organization of this type cannot be easily tapped physiologically, even by advanced techniques, lies in its nature as a feature of the brain acting as a whole, which leaves unique signatures only in the integral behavioral output from where they can be extracted by psychophysical means—and handed back to brain sciences for monitoring those physical foundations that have no direct mental reflection.

In accordance with the adopted line of attack, just let us suppose this to be true. The question is then: How can such signatures of holistic brain action effectively be extracted and pieced together to form a picture of concrete functioning? From physics we know that penetrating to fundamental laws has greatly been catalyzed by the reappearance of identical numerical constituents in various empirical laws. Thus, when tempting to pinpoint fundamental principles in mental activity it seems advisable to start with a try to find out whether something similar might be possible in psychology.

To suggest an answer and familiarize ourselves with the problems that are involved, let us have a brief look into common property of our science as to possible precedents.

When pondering about broadly applying empirical laws, the first to come to mind is Weber's Law. With minor formal modifications, the law applies universally, with a parameter, the "Weber Fraction", depending on modality and situational conditions. Importantly for our purpose, this universality includes the time domain in which Weber's Law was generalized for processing attributes as "scalar expectancy" (Gibbon, 1977) with two intuitive implications: First, since the law captures constancies of ratios, the alleged universal constant behind it should also signify a *relative* constraint. In a more ambitious formulation: The associated dynamic law should exhibit scale invariance in time. Second, because of its claimed universality this fundamental law must also be the building ground of Weber's Law for non-temporal dimensions. Consequently, in order to extract the universal constant, we may equally well build on time-free empirical relations.

Weber fractions vary across and within continua. Following the physical model, this prompts the attempt to proceed by combining Weber's Law with other well-established empirical laws, regardless whether time is explicitly involved or not. Given the huge body of pertinent evidence, Steven's Power Law suggests itself as an attractive candidate. Thanks to the enlightening work of Stephen W. Link (1992) the inner relatedness of both laws can be considered as given. Yet, thorny problems seem to remain when insisting on isolating universal invariants: As Weber fractions do, power-law exponents depend on a sizeable number of stimulus-context variables and procedural peculiarities; thus it appears that, before being able to go on, we have to extract stable dimension-specific constants, which implies an extensive preliminary program, not quite what we need at this point. Fortunately, due to major achievements by Robert Teghtsoonian (1971; also, Teghtsoonian & Teghtsoonian, 1997) there is a straightforward way to proceed. To briefly recapitalize: Focusing on the context variable "stimulus-range size", defined as ratio of the largest to the smallest stimulus included, Teghtsoonian examined magnitude-estimation studies in the literature. Selecting data for 24 ("prosthetic") continua from experiments in which the employed range size was maximal he found that the associated judgmental ranges were of approximately equal extensions. Best fit revealed the ratio $K = 30.2$. In other words, the judgmental scales span ranges of maximum extensions from the smallest value to about 30-times this magnitude.

With essentially the same logic applied to Weber fractions, Teghtsoonian ended again up with approximately equal figures for different continua. Regression for 9 continua revealed the estimate of $c \approx 0.03$. This suggests that Weber fractions relate in the same way to maximum physical range sizes as power-law exponents do. Beyond that it is worth noting that $1/K$ and c are of approximately equal value and thus meet the requirement of consistency at the upper range limit which suggests a super-ordinate unifying basis.

If ignoring some measurement subtleties of no bearing on the basic argument, the findings prompt the following condensed interpretation: Regardless of the natural ranges of variation and the sensory channels involved, physical magnitudes project onto one and the same area of central representation at which they are accessible to judgment. Furthermore, there is a unique representational mechanism at work placing all quantitative information onto a kind of yardstick of constant extension and, simultaneously, of constant relative discriminability at any point. In this understanding, it becomes apparent that the constants K and c give new impetus to the long-standing hypothesis of a central area of confluence, the *sensorium commune*. They also embrace constraints for a more precise portrayal of it.

In the perspective of the universality conjecture, this interpretation opens an optimistic outlook: Apart from mirroring a highly organized regime, the constants seem to reflect *upper limits* of processing that ultimately must be based on limits of the brain's capability to process and represent information. Why then, we can ask, should there always be different specific capability limits involved depending upon what kind of capability we focus on, say, to mention only a few, size of judgmental range in magnitude estimation, number of categories in absolute judgment, or number of objects that can be simultaneously attended to or estimated without counting, or number of items kept in working memory, and so forth? In this perspective, nothing appears as natural as to suppose that the vast variety of psychophysically identifiable limits ultimately reduces to a smaller number of more fundamental "inner" constraints of brain functioning. I can merely mention here as an aside that this idea, in fact, has already gained substantial empirical ground though physiological work of Arthur Lebedev and co-workers (Lebedev, 2001; also for further literature), who for some of the above limits demonstrated correlations with the dominant individual alpha frequency.

One need not agree with such expansions of Teghtsoonian's findings to share the feeling that the disclosure of two cross-modal and cross-dimensional invariants is so unique a finding that it ought to have triggered a wave of constructive research uniting psychophysics and physiology in the effort to squeeze as much as possible out of it. I admit a lacking overview here, but it appears to me that nothing of the kind and of this dimension has so far happened. Rather, related discussion seems to have stayed focusing on issues of replicability and validity. An extreme in the spectrum of opinions, and thus perhaps particularly informative on the state of affairs, is criticism by Laming (1997) who questioned the relevance of c. In short, Laming computed c from data in the literature with the result of 32 estimates spreading fairly uniformly over a range from roughly 1/10 up to about 10times Teghtsoonian's value. Taken at face their value, these figures seem to imply that the claimed relation does simply not absorb enough relevant variance to be considered a law.

Does this mean the game is up for c and thus for a corresponding invariant in a super-ordinate law of brain functioning? The remainder of the paper will provide us with an answer and will ultimately lead us, on quite an unexpected route, back to Teghtsoonian's relations.

Physical discovery heuristics and the methodological double perspective of psychophysics

For the most part, the answer will depend on locating concrete evidence in favor of constant c and its fundamental significance. However, to see why it should be searched for along the path we will actually be moving along and to appreciate the applied rationale, it is advisable to first form a rough idea of the logical difficulties behind the obvious lack of progress in a seemingly fundamental issue—my last preparatory consideration.

At the risk of carrying coals to Newcastle, let me once again consult physics: Besides paying attention to features of formal expressions, the general logic that physics shares with other natural sciences belongs to the indispensable prerequisites for a breakthrough to fundamental laws. Let me call it "discovery heuristics". From a whole bundle of features defining it, one is particularly characteristic: The fact that the researcher, if only in a rudimentary form, goes ahead from the very beginning in the fashion of hypothetico-deductive theorizing. To spotlight the relevance for the case at hand, consider the facts again: When plotting both sets of data in the order of their ranks it turns out that Teghtsoonian's estimates are so densely spaced that, in order to draft them by deliberate selection from data of the same spread as Laming's estimates, this pool would have to be several times as large as the sample available. Imagine now for a moment Marie Curie: Would she ever have thrown away even a small fraction of matter radiating several times as strongly as the remainders of Uranium production from which she had had it isolated? Comparison with Teghtsoonian's case is not as bizarre as it might appear at first sight: Above, we faced an argument seemingly depriving Teghtsoonian's relation of the status of a valid empirical law. Yet, closer consideration reveals that argument does not hold. His relation is simply not of the "normal" type to which applies to. Upper limits to that it refers *are not* variables anchored in the environment like the physical variables that Steven's law maps onto their psychological counterparts; they rather mirror inner constraints inherent to, and imposed by, the brain. Thus, whether appreciated or not, already in adopting a variable like the maximum employed range as a criterion for data selection amounts to pursuing a hypothesis about a system constraint of brain functioning. In other words, Marie Curie's physical discovery heuristics applies; the higher density of estimates in the vicinity of Teghtsoonian's overall mean can rightfully be regarded as *tentative evidence in support* of the hypothesis and thus taken to encourage further search of more evidence.

In addition to its deductive character, there is another crucial feature of physical discovery heuristics of relevance: highly selective reference to the evidence. In the extreme, even *one exceptional case* in an ocean of contradictory phenomena put intuitively in the same category can suffice to proceed further. For instance, in establishing quantum mechanics, it proved to be extraordinarily useful to consider discrete spectra *in isolation* from continuous spectra or even to focus on a particular regularity, Balmer's series, in separation from all the rest. The chance to ultimately arrive in that manner at fundamental laws proper has its basis in the phenomena themselves, more precisely in the fact that configurations like atoms or grids of atoms constitute contingent conditions under which the action of fundamental laws leaves sufficiently unique traces. The status of the corresponding empirical regularities in the capacity of mediating links to fundamental laws is the same as of those underlying taxonomic rules in other sciences. In the widest sense of the word their formal descriptions constitute *"taxonomic"* rules, with the qualification that they are specified strictly quantitatively.

For our attempt to pinpoint quantitative universals it is of crucial importance to understand why nothing comparable has so far gained significance in psychology. Fechner, pondering on factors that aggravate the job of psychophysics as compared to physics (see this paper's motto) located as a major reason—in my words—the demand that every trace of mental activity is to be appreciated as a reflection of the outside world and our relations to it and simultaneously as mirroring the prerequisites in the brain making this reflection possible. In this polarity, the development of our science has led to a strong bias toward the first, the *functional* aspect, at the cost of the second, the *systems* aspect. A major consequence of this emphasis on functional relationships is that the action of the processing system becomes visible only in terms of limits, range limits in Teghtsoonian's case, speed or capacity limits in other cases. In fact, processing limits have become widely perceived as marks indicating the border at which the job of psychophysics ends and the realm of sciences working on the physical substrate begins. One of the most unfortunate consequences of this voluntary, self-imposed, abstinence of the psychophysicist is a fairly widespread collective amnesia for stable and highly differentiated, but functionally opaque, effects such as Fechner colors, which together with countless phenomena classified as "illusions" have been put into a corner of curiosities of no functional significance. Clearly, to be absolutely explicit on that, if the claim of holistic organization is correct, this attitude misses out on a central point. When adopting physical discovery heuristics for psychophysics, there is just no basic difference between functionally "transparent" exemplars of empirical relations and functionally "opaque" non-exemplars. The only thing that counts is the taxonomic "power" through which a phenomenon may assist in unveiling more basic regularities. Quite analogous to spectra in physics, this power can be expected to be higher for richly than for scarcely structured regular relationships. This is what the basic idea behind the Taxonomic Time-Quantum Model (TQM) to be now considered constitutes.

The Taxonomic Time-Quantum Model (TQM): Basic findings and claims

Natural constants are absolute. Quite in accordance, for the present enterprise, identification of absolute constants of brain functioning is our first primary goal. As for the dimension of time, the idea of a universal absolute constant is at least as old as Fechnerian psychophysics and has become known as the “Psychological Moment”. A later closely related notion, the assumption of a constant minimum of perceptual duration, had been around for decades and was ultimately rejected (e.g. Allan, 1976). Pertaining criticism, though, has been of no concern to major results of the less well known European line of research.

Experiments by Brecher (1933) provide a starting point for us: With a method of limits, he determined the frequency at which sequences of separable events fuse into sensed continuous vibration. Of lasting relevance are three findings: (1) Confirming earlier findings in vision and audition, Brecher found the “fusion threshold” at 55 ms, with an SD across 14 individuals no larger than ~2 per cent; (2) the same value obtained for areas on the skin differing as dramatically in terms of receptor density as the back and the tip of the tongue; (3) drug administration revealed massive effects, generally exhibiting substance-specific time courses with apices up to 50% above the base-line value. Finding (1) implies that a genuine universal, if existing, should also exhibit but a fairly small individual variability; (2) demonstrates convincingly that the origin of the constant is central rather than peripheral, which is in agreement with presumed features of the universal constant; (3) reemphasizes the biological nature of Brecher’s constant as opposed to a leading role of external pace makers. In addition, it is worth noting that—in line with Teghtsoonian’s results—the three findings suggest that differences of sensory inputs in space, time and modality become balanced in subsequent processing so as to allow for integration into a unified central representation.

The Time-Quantum Hypothesis (H1)

Despite its impressive invariance properties, Brecher’s epoch did not stand the test of universality. In fact, time thresholds and other discrete characteristics have been found to vary as functions of context variables of various types. Yet, under some procedural conditions, striking integer-ratio regularities have been pinpointed in this variation. Due to their significance in uncovering deeper regularities, I will refer to them as “quantal structures”.

As it appears, the first to come across a structure of this type and to stress its significance was Georg von Békésy (1936, 1960). Building on work by Brecher (1934) in audition, he examined absolute thresholds in sinusoidal low-frequency sound. Specifically, starting at sub-threshold intensity, frequency was—while keeping intensity constant—continuously increased until the stimulus was perceived. This procedure was repeated at various levels of intensity. Plotted against frequency, absolute thresholds thus obtained exhibit a strikingly abnormal course. As shown in Figure 1 at the top, it is that of a smooth function interrupted by sharp discontinuities, altogether 11 vertical breaks of different heights. As von Békésy noted, the progression of these “spectral lines” can be dissected into regular sub-series, i.e. according to the above definition into quantal structures. Most salient by height of breaks is a series of discontinuities which, including Brecher’s period, comprises the cycle durations of ~222, ~111, ~55.5, and ~26.5 ms. In a taxonomic view, it is important that members of this series, in different combinations, have frequently been observed in many other specimens of empirical functions in which quantal structures can be identified. Let us therefore refer to it as “index series”. The middle panel presents an example from a study by Treisman, Faulkner, Naish, & Brogan (1990) in which a driving technique developed by Treisman and coworkers (see Burle, Macar, & Bonnet, 2003; for an overview) was employed.

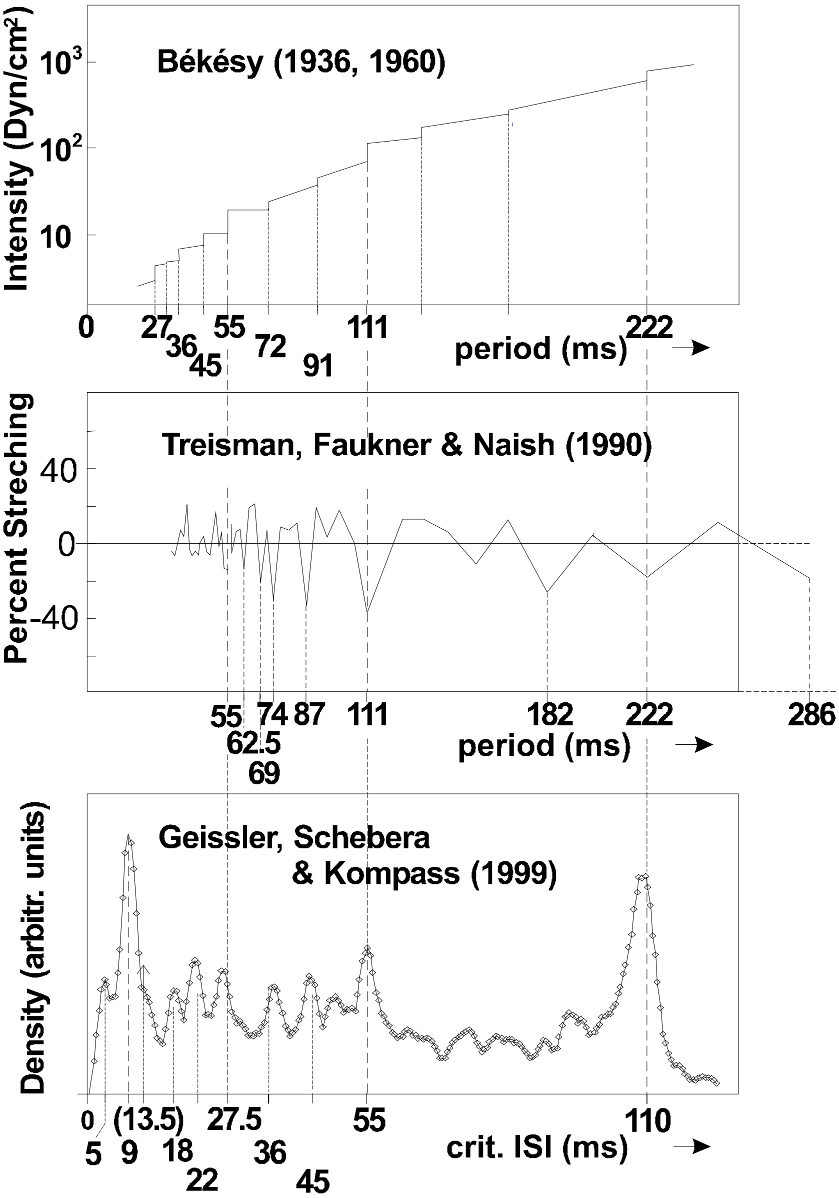

Fig. 1. Data profiles from three paradigms exhibiting partially overlapping quantal structures. Note the change of scale in the panel on the bottom. The arrow at ~13.5 ms is to indicate a mode smoothed away by local averaging. Further explanations in the text

The term “driving” here is to indicate that the examined effects are induced by uniform series of short clicks or flashes of light. Note that in this example quantal structures reside in points of maximum reduction of judged duration.

The bottom panel displays findings by Geissler, Schebera, & Kompass (1999) in beta motion, the apparent movement seen under appropriate constraints when visual stimuli are presented sequentially at different positions. For each of twelve stimulus exposure durations (ED) kept fixed, ISIs were adjusted downward and those critical ISI values (cISI) determined at which seen motion suddenly gave rise to perceived flickering. In the diagram which presents the cISI distribution collapsed across EDs, we observe quantal structures in the positions of the peaks that indicate the points of maximum frequency of motion breakdown from 46 participants. Note that the abscissa is scaled up 2:1 relative to the upper panels.

Taken as one piece of evidence, these results establish relations of a status quite different from that of “normal” empirical relations: First, the close convergence of data from three independent sources in members of the index series alone makes the hypothesis of a common origin practically irresistible. In the combinatorial and basically Bayesian view of discovery heuristics, this constraint is so powerful that it does not matter that in a much larger number of situations probably no regularities of this kind are obtained.

Closer inspection reveals a second even more surprising finding: When determining greatest common divisors (GCDs) separately for the three sets of data it turns out that they closely converge. In the face of common quantal regularities, this may not seem too surprising. However, a plot against a unit of 4.5 ms as an approximate super-ordinate GCD shows that the elements in their overwhelming majority conform to four doubling progressions originating at the prime multiples 1, 2, 3, and 5 of this super-ordinate GCD. This reminds us of our main objective: A unit of this size and properties, given that it gains support by further evidence, offers itself as an ideal candidate for a modular time unit of universal significance. In comparison to Psychological Moments of the order of 55 ms (Brecher) or 110 ms (Stroud) that have been proposed, this small epoch has the great advantage of being located on the lower end of a scale for which it provides a natural unit. Vicarious occurrence of integer multiples of it can be seen as evidence indicating that, in adjustment to the sizes of time intervals relevant in a given situation, different integer multiples of the elementary unit become actually employed. This is what in essence has come to be called the *time-quantum hypothesis*. The assumed quantal epoch of which any period of a quantal structure is supposed to be an integer multiple *and* the adopted more precise estimate of 4.57 ms have been termed the *"time quantum"* and designated by the symbol Q_0.

Since its first statement in a provisional (Geissler, 1985) and in its present more elaborate form (Geissler, 1987, 1992), the hypothesis has slowly but steadily gained support through a substantial body of evidence based on contributions from different research groups. The examples of Figure 1 merely provide a particularly easy demonstration of the quantum constraint. The actual developments that have led to the hypothesis and revealed an underpinning stable enough to allow further inferences were driven by findings from recognition paradigms. For lack of space, I have to concentrate here on a few examples and to refer the reader to brief surveys by Geissler & Kompass (2003) and Kompass (2004). An important initial impetus came from a pattern-masking study by Vanagas, Balkelite, Bartusjavicus, and Kirvialis (1976), so far the only experiment that provided direct evidence that mental processes indeed proceed in small quantal steps of the order of some milliseconds. Their crucial finding consists in percentage-correct trends exhibiting periodic relapses strikingly reminiscent of the courses known from the famous Franck-Hertz experiment that for the first time directly demonstrated the quantal nature of energy emission and absorption. Reanalysis of data from 8 participants revealed a central value of 9.13 ms (Geissler, 1985), half of which is the now adopted standard value of Q_0. Once available, the estimate prompted detection of near-integer relationships in data sets of quite different character. Most surprisingly, this included epochs from reaction-time experiments. As an example consider the means from eight item-recognition experiments with digits by Sternberg (1966, 1967a, 1967b) and from training series replicating the basic design by Marianne W. Kristofferson (1973) of 36.85 ms and 36.20 ms, respectively, which deviate by less than 1% to both sides from 4×9.13 ms = 36.52 ms. Similarly, epoch durations of 220 ms found, for instance, by Klix and co-workers in analogy recognition (cf. Geissler, 1987) coincide almost exactly with 24×9.13 ms = 219.12 ms. Note that the latter value is close to the largest element of the index series (~220 ms) and the smaller, according to 36.52 ms = 109.56 ms/3, branches as a segment from the index element of 110 ms (cf. Puffe, 1990, Bredenkamp, 1993, Petzold & Edeler, 1993, and Bredenkamp, 2003). Evaluations based on clustering of estimates for individuals (Geissler, 1990; Petzold & Edeler, 1993) suggest that under the normative conditions of group experiments individual performances fluctuate approximately uniformly between adjacent quantal levels centred at preferred multiples of Q_0. This makes plausible that group means can converge at quantal levels despite a variability of RT data so much larger than Q_0.

Indications of conclusiveness

To appreciate the current status of the time-quantum hypothesis more fully, I have to briefly go into additional supportive results which are complementary in the sense that they compensate potential weaknesses of the evidence presented and together with it shape a much more complete and theoretically satisfactory picture.

The way so far described to identify an absolute unit in mental timing involves two problems: First, a unit derived as a GCD from strong serial regularities might be deceptive and it would at least be more convincing if its presence could be demonstrated in irregular data samples. Second, as the reader may have noticed the procedures employed in the psychophysical paradigms—with the exception of the driving paradigm—are versions of Fechner's "method of limits" that by today has gone out of use, because it is considered to be subject to serious biases. Its employment is, however, imperative, because detection of motion breakdown at the very moment it occurs is a necessary condition to reveal its quantal character. Yet, the method always produces overshoots which have to be corrected.

Scrutiny of individual difference distributions offers itself as an elegant means to check upon the presence of period Q_0 while circumventing the two problems. In the case of beta motion, Geissler et al. (1999) considered fluctuations between trials and their identical replications. The fit for different quantal-lattice distances indeed revealed indications of a periodicity of ~4.5 ms cycle duration (Figure 2, left). With a different procedure revealing a more precise estimate, Kompass (2004) replicated this finding. For comparison, evidence of a micro-period of about the same duration extracted from RT data obtained in a same-different experiment with geometrical patterns (Lachmann & Geissler, 2002) is shown in the panel on the right of Figure 2. To detect periods as small as ~ 4.5 ms in RT data, large numbers of differences between adjacent trials from 55 participants at high stages of training were evaluated. The demonstration of their presence in the fine-grained local patterning of the quantal structures not only strongly supports the notion of a universal period Q_0, it also eliminates other accounts of the global quantal structures, for example their explanation as harmonics of the pacing rhythm of a central clock as suggested by Treisman and co-workers.

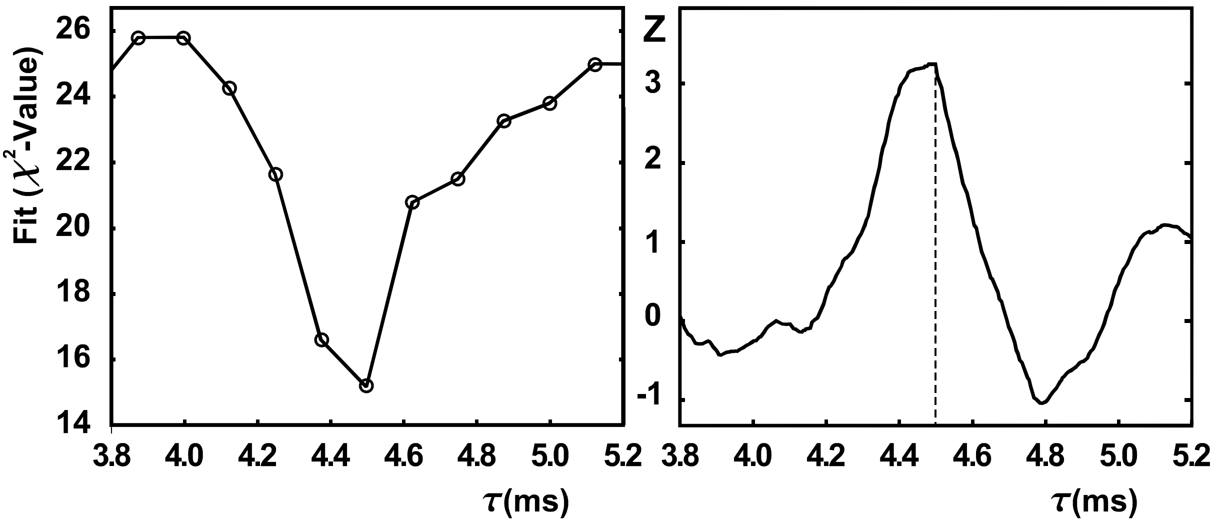

Fig. 2. Fits of difference distributions to quantal-lattice distances τ for simultaneity thresholds in beta motion (left) and averaged inter-trial RT differences (right). See the text for details.

Table 1. Ideal quantal boundaries and empirical RT maxima and minima of "plain" driving in three paradigms (shaded part) and synchrony priming. Explanation in the text

ms/Hz	**$4Q_0$**	Ma_1	Mi_1	**$5Q_0$**	Ma_2	Mi_2	**$6Q_0$**	Ma_3	Mi_3	**$7Q_0$**	**$10Q_0$**	Mi_4	Ma_4	**$11Q_0$**
T	18.3	20.4	21.3	22.9	23.8	25.6	27.4	29.1	30.3	32	45.7	47	49.4	50.3
F	57	49	47	43.8	42	39	36.5	35	33	31.5	21.9	21.3	20.3	19.8

Another important aspect can be touched upon only briefly: The above evidence pointing to a spontaneous fine-grained temporal organization in various focal tasks raises the question of stability of the quantal constraints under non-focal stimulation. From the example of Figure 1 it may appear that an inducing flicker of > 20 Hz overrides any regularity indicative of quantization. However, detailed evidence shows the contrary, namely robust stability of quantal bounds. Table 1 illustrates this by data from quite disparate paradigms. The shaded area refers to RT effects of "plain" driving from two Simon-type situations and one Sternberg paradigm, schematically summarized according to Burle and Bonnet (2003). The rest of the table refers to "synchrony priming", a specific phenomenon discovered by Mark A. Elliott (cf. Elliott & Müller, 2004). Roughly, synchrony priming is a speedup in the detection of (in the experiment Kanisza-type) patterns caused by spatially congruent, consciously not perceived, figural elements flashed in temporal synchrony prior to the focal stimuli. The two paradigms suggest "double-wave" structures that nicely fit into the intervals spanned by $4Q_0$ and $7Q_0$, and by $10Q_0$ and $11Q_0$.

Quantal-Range and Prominence (Connectedness) Hypotheses (H2 and H3)

An outline of the two remaining hypotheses of major significance should and can be shorter.

H2, the *Quantal-Range Hypothesis*, is fairly natural: Intervals made up by integer multiples of Q_0 should have a definite upper limit M. To cover intervals > MQ_0, the already introduced idea suggests itself that besides Q_0 integer multiples qQ_0 are possible units. How large is M? A sophisticated first guess was M = 24 (Geissler, 1985). Later evidence from duration discrimination (Kristofferson, 1990) and item recognition (Petzold & Edeler, 1993) prompted the hypothesis M = 30. Perhaps most convincing is the periodic structure visible in plots of maximum operation times in short-term memory calculated by Puckett and Kausler (1984; cf. Geissler, 1987) and Puffe (1990). It reveals terminations below gaps at ~135 ms and~275 ms, corresponding to $30Q_0$ and $2 \times 30Q_0$, respectively, and an upper limit 3-4 % below $4 \times 30Q_0$. To indicate the quantal ranges corresponding to different unit sizes R_1, R_2, R_3, R_4, R_5, etc.. have become standard symbols.

H3, the *prominence or connectedness hypothesis*, concerns the status of the components forming quantal structures. Previous descriptions in the form of rules (cf. Geissler, & Kompass, 2003) were anchored at a particular major component of the fissured profiles as reference value to which the fixed status of a Psychological Moment was attributed. Apart from that, the rules focused exclusively on the regularities in terms of quantal time values on the abscissa. However, the situational variation of the profiles carries most of the information on the impact of stimulus regimes and task demands. (So one can understand why functionally oriented research never paid attention to the rules.) TQM, in due consideration of the fact, adopts a radically different view: It puts the architecture of the profiles in the centre by assuming that each admissible multiple N is characterized by a specific prominence value delineated by "internal", system-related, constraints. Situational variation of observable profiles is considered as a consequence of interaction of the prominences with "external" constraints imposed by situational determinants.

An important cue for specification of prominences was the salience of components of ~110 ms duration in many quantal structures. The explanation of this puzzling privilege is based on H1. According to H1, all periods sufficiently close to this duration correspond to the multiple $24Q_0 = 24 \times 4.57$ ms = 109.7 ms. Since the factor 24 is the only specificity of this epoch within R_1, it follows that the basis of the particular prominence of the index line must be a property of this very number. In fact, it turns out, that from among the numbers 1 to 30 the number 24 has the largest set of divisors! Why should this be important? The most likely answer is: because it grants the greatest number of options in forming quantal structures by relating to other multiples. Putting it differently, it reveals the highest degree of connectedness. From Figure 1 it is obvious that short periods < 30 ms may also be prominent. To account for this observation we have to assume that connectedness is a symmetric relation (see Geissler & Kompass, 2003) indicating the number of ways in which a given N relates to other multiples. This defines prominence $\Pi(N)$, a function that proves to be a most forceful tool for taxonomic inference and theorizing.

Quantum-Wave Theory (QWT): Beginnings of a theory based on universals

Scientific progress is driven by anticipatory beliefs: In the second volume of his "Elements"—written at a time nerve energy was yet supposed to propagate at speed of light—Fechner developed the idea that mind has its basis in wave-like carrier processes. He was fairly specific about that: Drawing on Fourier's just advanced theorem, he tacitly assumed the property of undisturbed superposition. Taking profit of a treasure of careful observations, he suggested that it is *modification* of continually ongoing spontaneous activity in the proposed carrier medium through which perception and cognition come into existence.

The enterprise to be outlined here in a very compressed form arrives at the same claims—wave-like character of carriers of mental activity (or simply "carriers"), their undisturbed superposition and selective amplification—just by inference from TQM constraints and from Lebedev and his co-workers' findings. Preliminarily, I refer to it as "Quantum-Wave Theory" (QWT), half borrowed from Link who was the first to acknowledge that epochs of the duration Q_0 may just be of the right order of magnitude to account for step lengths in judgmental processes. It is one of the convenient features of QWT that its basic axioms can be stated in complete parallelism to substantive axioms and measurement assumptions of quantum mechanics. However, this does not imply the possibility of *reduction* to the physical theory of quantum mechanics nor even its calculus.

Carrier representation: A preliminary implementation of QWT

Today, the existence of brain waves is commonplace; the serious problem remaining is that almost any evidence of their functional significance is of merely correlative nature. By contrast, the quantal epochs and associated cascaded range structures introduced by TQM in conjunction with the preference structure of prominences induce a net of taxonomic relations which for the first time provides a chance to decipher elements of the temporal "coding language" of the brain. To translate this promise into action, let us here adopt a highly simplifying carrier implementation of the TQM hypotheses assuming that (1) quantal periods $q \times Q_0$ are represented by carriers of this cycle duration, extending in time without limitation; (2) the emergence of quantal structures is modelled by hierarchies of "phase-coupled" carriers of different cycle durations or, simply, carrier hierarchies.

What we need in addition is a plausible principle to impose constraints that capture the action of contingent conditions characterizing a phenomenon and task at hand. This is tricky, because we will have to challenge deep rooting habits in psychological theorizing to refer in a non-committal, and often thoughtless, way to physiological foundations. For an attempt capitalizing on psychophysical invariants any such reference would be self-contradictory and thus paralyzing. In this situation, a stratagem is of great help that has stayed the same from the time of Leibniz and Newton to the cosmology of our days. I will call it here "Principle of

Progressive Constraining” (PPC) and will introduce it essentially by working with it. Roughly, PPC captures, in a logical form analogous to Newton’s postulate of inertia, causation of effect as minimal deviation from a uniform ground state.

Prediction of global wave formations: A check of consistency

Once the universal constants are known, a theory based on fundamental laws must reveal predictions in absolute terms without any parameter fitting. Accordingly, and quite embarrassingly from the point of view of traditional theorizing in psychology, QWT even in its provisional implementation should cover universal formations of physically detectable cyclic brain activity and their natural internal dissections and this must be possible in terms of *absolute* cycle durations or frequencies—a demand of unprecedented strictness!

How can we pinpoint an appropriate specification of possible carrier formations as based on hierarchic phase coupling? Following PPC, the cue requirements are not difficult to guess: First, the generating system must act on the basis of a production rule; second, to grant uniformity, the rule should be recursive; third, the result should be maximally dense.

To spot the set of carriers meeting these requirements, first consider the multiples 1 to 30 independent of range-specific timing. Note that the elements of the subset $16 \leq N \leq \mathrm{M} = 30$ have only “downward” connections. Consequently, all multiples < 16 can be generated from them by integer division. Analogous considerations hold for multiples < 16, yielding further dissections. But the multiples 16 to 30 have a privileged position of “generators” for each of them. Let us now switch to absolute temporal specification: Here we have to note that every R_2, R_3, R_4, R_5 etc.. can uniquely be generated by integer magnification from R_1 and only from R_1. The requirements of recursive generation and maximum density reduces this set to the “doubling” sequence R_1, R_2, R_4, R_8, R_{16} etc., which is the manifold we were searching for. Let now G_1, G_2, G_4, R_8, G_{16} be the range-specific “generator sets”, then it follows that all larger sets can be generated from G_1 by integer magnification by a factors 2^n. This formal relationship thus puts G_1 in the privileged position of a universal generator set.

All that has been said should hold for the isomorphic images in terms of the assumed carriers. The question is thus: Is there a distinct formation of physically recordable brain activity matching the predicted preferred interval G_1 of cyclic carriers? The answer is a definite “Yes”. Note that, expressed in milliseconds, the corresponding sub-range extends from 16 × 4.57 ms = 72 ms to 30 × 4.57 ms = 137.1 ms. Converted into frequencies, this yields the interval 7.3 Hz $\leq f \leq$ 13.7 Hz. This range agrees fairly precisely with the standard text-book definition of the strongest electric activity recordable from the scalp, the alpha band of the EEG (8 – 13 Hz). Agreement turns out even better when referring to the range as delineated by research addressing the functional significance of alpha activity which is 7.5 Hz to 13.5 Hz (Lebedev & Lutzky, 1972; Lebedev, 2001; also for other references). As Table2 illustrates, there is fair agreement also for the next two predicted segments with other EEG bands at lower frequencies. The same holds for the dissected sub-ranges at higher frequencies.

Pred. Sub-Range (Hz)	EEG Band	Frequency Range (Hz)
$7.3 \leq f \leq 13.7$	Alpha	$7.5 \leq f \leq 13.5$
$3.7 \leq f \leq 6.8$	Theta	$4 \leq f \leq 7$
$1.8 \leq f \leq 2.3$	Delta	$0.5 \leq f \leq 3$
$14.6 \leq f \leq 27.4$	Beta	$14 \leq f \leq 30$
31.9 Hz $\leq f \leq 54.7$	Gamma	$30 \leq f \leq 50$

Table2. Predicted sub-ranges and corresponding definitions of EEG bands. Note that the pragmatic definitions may considerably vary depending on the special research purposes.

The discernable hierarchies of carriers derived *solely by inference from behavioral evidence* thus stood the test of comparison with taxonomic EEG formations of brain activity. Relatedness to EEG formations prompts further conclusions and explorative steps. To mention only two issues of particular importance: First, it calls for a closer account of the role of Q_0 in relation to oscillatory activity. An interpretation by Kompass (2004) suggests that chains of delays of duration Q_0 accomplish stabilized oscillation regimes thereby providing building blocks for compensation of "undesired" retardations, a mechanism so far not considered in brain research. Yet interestingly, the only large-group study in brainstem transmission times (cf. Geissler, 1992) has revealed values practically coinciding with Q_0. The second issue is of significance to psychophysics: The cascade of bands of cyclic activity suggesting itself argues against the central clock still widely assumed in human timing research.

Prediction of global distributions: Simultaneity thresholds in apparent motion

The perhaps most uncommon feature of modeling based on universals is that random characteristics of perceptual-cognitive performance emerge as automatic byproducts of delineation in terms of situational conditions and task demands. While in familiar modeling random variation is either implicit to the input or embodied as internal noise, in QWT it is conceptualized as a product of ambiguity due to incomplete constraining of available options for responding. A far-ranging difference to the common view resulting as a remote consequence from this conception is that distributions cannot be dealt with anymore as fixed primaries, but are rather to be considered as situation bound and subject to task-related selection and optimization.

If random variation is part of predicted relations, PPC should be instrumental for its effective delineation. To illustrate what is implied, I am referring to two studies on simultaneity thresholds in apparent motion carried out in Leipzig. In both instances, the situation can be described as follows: The stimuli were presented in cyclic alternation and ISI adjusted downward for fixed exposure durations (EDs). Adjustment started above some upper bound, say C_1, where apparent motion is stable, and stopped below some lower bound, say C_2, where only flickering is seen. The interval between C_1 and C_2 constitutes a zone of transition in which the motion percept is "meta-stable", tending to break down. This is where the PPC rationale comes into play: The quantal-lattice points located within the zone of transition are the options competing as time slots for motion breakdown. Given constant speed of adjustment, there is only one factor affecting uniformity: number of alternative realizations of the options, i.e. the prominence values $\Pi(N)$. PPC then maintains that all realizations are of equal right across time slots. The prediction is thus that the time slots are accessed in proportion to their prominence. This should hold for all segments along the entire range of critical ISIs (cISIs). As has been shown by Geissler et al. (1999), this prediction covers the empirical profile of the beta motion data shown in Figure 1 in detail. Taking into account that the derivation, among other things, ignores individual differences, a correlation of r = 0.83, considered as a non-statistical measure of similarity, indicates a reasonable degree of relatedness. However, the actually important point is that on a hypothetico-deductive basis the prediction captures a "non-transparent" regularity behind an on the surface irregular pattern that is defined on 23 quantal-lattice points on the abscissa. This includes that the correlation is not resistant to even smallest translations of the predicted function along the abscissa (for shifts of $+Q_0$ and $-Q_0$, r drops from 0.83 to 0.42 and 0.02, respectively). The likelihood that a fundamentally different deductive account could do the same job is astronomically small. An even more instructive example of the same type is provided by gamma motion, the apparent waxing and waning of an object seen when a visual stimulus is presented intermittently at the same location. Not only looks the fissured profile of simultaneity thresholds shown in

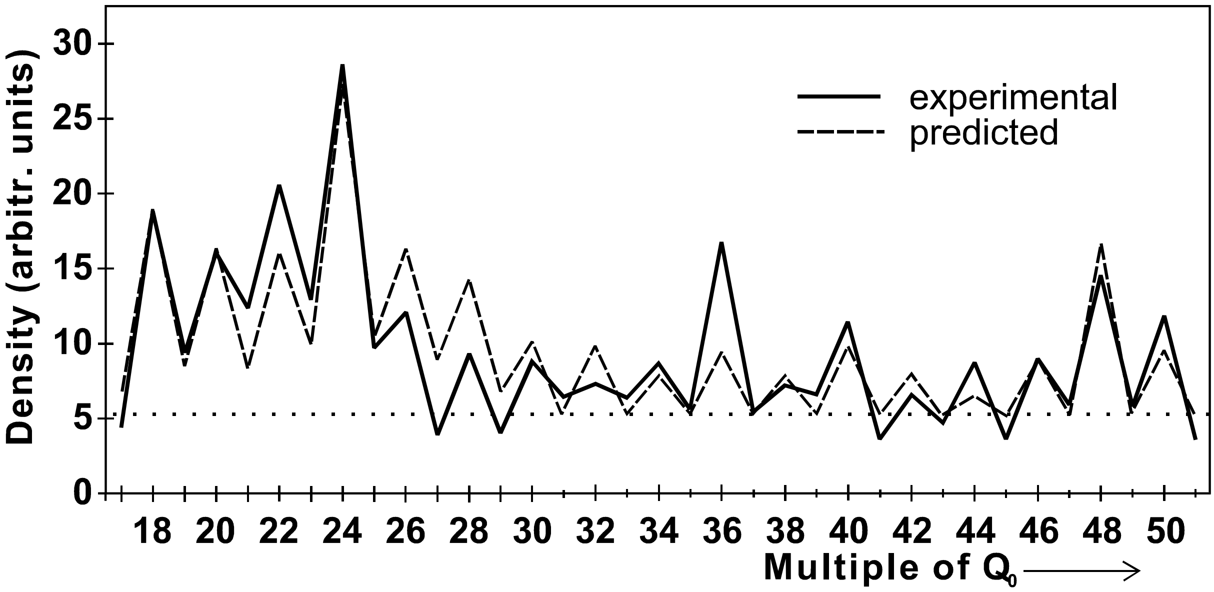

Fig. 3. Empirical and predicted breakdown frequencies of Gamma Motion for 25 cISIs (in Q_0 units). Note the high base level (dotted line) probably due to breakdowns right after C_2.

Figure 3 very different, but the distribution extends over a genetically fixed range about twice as large as for beta motion thus covering the largest part of R_2. The larger range of variation has two minor procedural consequences: First, local random variation exceeds the elementary quantal-lattice distance Q_0 and can thus not be ignored anymore. To account for the blending of adjacent quantum levels, ideal point predictions had to be replaced by small, best fitting, distributions. Second, to keep the duration of the series within the limits of the preceding experiment in beta motion, speed of adjustment had to be more than doubled and the resulting overshoots taken into consideration. Another consequence of the enlarged range is of fundamental significance: So far we have not paid attention to the fact that quantal ranges as defined massively overlap and that, as a consequence, assignment of quantal epochs to ranges is not unequivocal, unless there were additional constraints enforcing uniqueness. Since ED sequences were randomized, the experimental regime did not impose any such a constraint. Hence, simple Π-based predictions proved to be qualitatively incorrect. According to PPC, we rather have to assume continual superposition of both the R_1- and the R_2-related representations and thus (in R_1) to replace $\Pi(N)$ for every even-numbered N by the "composite" prominence $\Pi^*(N) = \Pi(N) + \Pi(N/2)$. This yields the predictions indicated by the dashed line in Figure 4. With r = 0.83, the same relatedness is found as for beta motion. The result greatly strengthens the above conclusions.

Substantive relevance for motion perception: A further type of constraint

One may acknowledge the account of quantal breakdown distributions and still be wondering about the "functional" relevance of the explanation—in the given case for the understanding of a facet of motion perception whose ecological significance is unquestioned.

Let me address this issue in a compressed fashion enforced by lack of space: As a basis of beta motion, low-pass filtering in the brain has widely become accepted during the last decades. This is tantamount to the assumption that frequency of stimulus alternation is the relevant independent variable. The corresponding cycle duration is the sum ISI + ED. Thus the upper frequency bound of the filter demarcates the simultaneity threshold T according to: *cISI* + *ED* = T. Hence the theory predicts a slope of 1 for mean *cISI* as a function of *ED*. The left panel of Figure 4 presents the mean trends for beta and gamma motion (open and filled

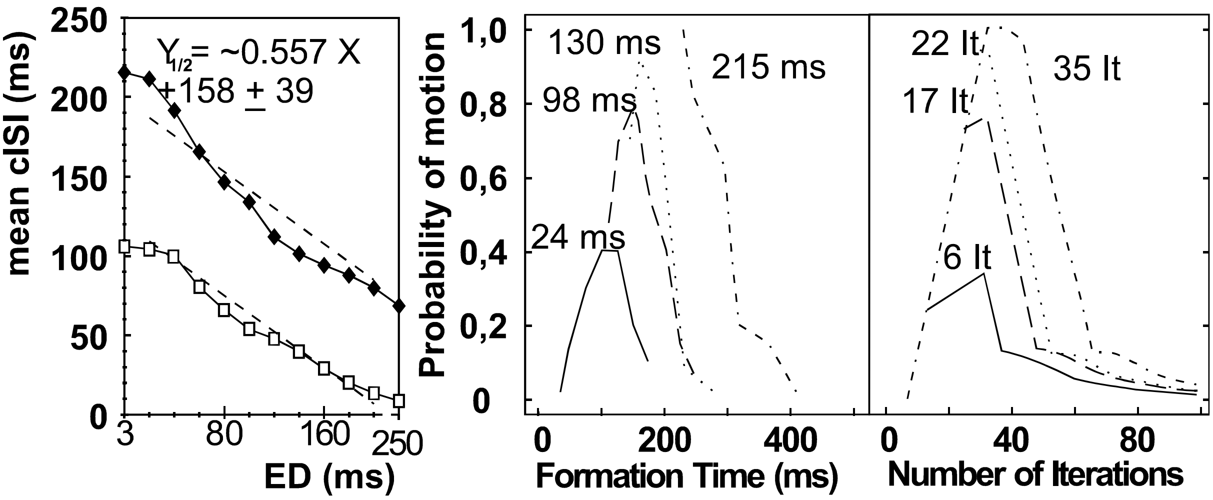

Fig.4. Explanation in the text

symbols). Regression for the approximately linear parts reveals *cISI* + 0.56 × *ED* = Δ, with Δ ≈ 120 ms and ≈ 200 ms, which is qualitatively at odds with the prediction. QWT suggests a very simple alternative based on two assumptions: First, ISI and ED enter with weights that refer to the respective ranges in which they are represented, i.e. with the relative contributions $cISI/Q_0$ and $ED/2Q_0$. This predicts a factor of 0.5. Second, the right side of the "construct" equation must be given by the theoretical upper bounds $30Q_0$ and $60Q_0$, respectively. Written in a time-free form, the equation for beta motion thus reads: $cISI/Q_0 + ED/2Q_0 = 30$. Note that this is a relation of the capacity-sharing type: The limit M = 30 defines the maximum number of available units that ISI and ED together can occupy. How can we get from here to the observed trends? This depends on the conditions for which the equation is to be implemented. In the case of the method of limits considered so far wave superposition, using the language of quantum theory "collapses" at the moment transition occurs. For beta motion, it was shown by simulation (Geissler, 2000) that for this condition the Π-theorem reveals even fine details of the empirical trend. In particular, the flat segment from ED = 3 ms to ED = 40 obtains as a consequence of "absorption" at the most prominent multiple N= 24 of Q_0. By contrast, for the classical standard paradigm, in which the stimuli are presented in pairs, QWT predicts that the *probability to see motion* must be proportional to the number of superimposed carriers supporting this state. Informative on whether this prediction applies are data by Kolers (1972) displayed in the double panel of Figure 4 on the left. The right part presents the results of a semi-empiric simulation by Bettina Altmann (see Geissler & Kompass, 2003). Computation is based on a difference equation which includes a delay term imposing a quantal constraint upon carrier persistence and a term of self-catalytic growth of number of elicited carriers. Notably, fit to Kolers' data reveals consistency with M =30. (Note also the predicted tails not easily obtained by other models).

The results presented for the functional relation governing the representation of motion suggest another type of internal constraint than for local breakdown. What is important, this newly found constraint embodies the same fundamental constants Q_0 and M as the constraint of hierarchy formation. Another aspect deserving attention is that depending on the type of "external" constraints enforced by stimulus regime and task demands, one and the same regular relation which on the construct level represents a class of processes may give rise to observable response patterns of widely varying complexity.

QWT: A provisional summary of essentials

The experience from these and the previous applications enables us to draw an interim picture of the approach that besides pointing out commonalities also identifies characteristic specific differences between it and the physical prototype: First, there is a carrier medium to be assumed—the medium of Fechner's "Psychophysical Process"—, very probably a large collection of wave-like entities portrayable as cyclic activities that coexist in undisturbed superposition. Second, there are basic types of "internal" constraints—constants like Q_0 and M and relational constraints like hierarchic phase coupling or range sharing—that constitute the uniform basis from which structures emerge through mental self-organization. Their formal counterparts in physics are the natural constants and fundamental laws. Third, we have "external" constraints acting on the manifolds of possible mental structures. They are the counterparts of initial and other side conditions entering into the equations of the fundamental laws. While for a physicist it amounts to no more than a metaphorical way of speaking to say that contingent conditions "select" the solution applying in a given case from the total of possible trajectories, in the psychological analogue "selection" applies, as the above applications of PPC have suggested, in the literal sense of a completely random choice between relevant options, very much like in natural selection.

Of course, the aspect of selection from pools of carriers is only one of the basic issues involved. Another facet of central significance to modern psychophysics that could not be touched is the implementation of inferences about signal attributes in judgmental processes.

Irremovable uncertainty (fuzziness) and limited temporal coherence: The origin of Teghtsoonian's constants

There remains a crucial step to be made to close the circle to where we started from: So far we have neglected *real time*. However, clearly, epochs like time thresholds are discrete intervals with a beginning and an end. The key assumption by which QWT accounts for real-time dynamics was anticipated by interpretation of M as a temporal coherence limit (Geissler, 1985, 1987). It describes boundary M as a consequence of irremovable uncertainty (fuzziness). A wave selected in terms of its cycle duration and amplified at a certain point of time has no sharply defined frequency; it behaves like a mixture of carriers of closely adjacent frequencies. Due to undisturbed superposition, phase shifts among components increase and after M increasingly fuzzy cycles the phase distribution becomes random. What makes this hypothesis—with possible slight modifications of its specific form—so convincing is that in all known cases in which temporal quantization has been documented in sufficient detail over a larger interval, upper range bounds are approached with continuously increasing local variability (cf. Geissler & Kompass, 2003). As was mentioned, the switch between discrete ranges always happens at the same multiple M = 30, presumably due to stabilizing chains of delays. There is not yet a full account of how this value transfers to non-temporal dimensions. However, agreement of M with Teghtsoonian's constant K can rarely be coincidental. Apart from their numerical agreement, their common function as upper range bounds points to their identity. In addition, according to QWT, K and c can be expected to be merely two sides of one and the same thing, namely the irremovable fuzziness of the absolute constant Q_0. This provides also a possible explanation of why empirical estimates of c are so variable: First, any deviation from ideal initial synchronization enlarges dispersion. But more excitingly, variability can also fall *below* the norm value as the trend of dispersion of cISIs in beta motion in Figure 5 shows: There are three positions indicated by arrows at which the Weber-Line trend is interrupted by local minima *and* where differences between individuals become minimal. Note that this happens in close vicinity of the *most* prominent multiples 2, 12, and 24. This finding points to the surprising possibility that a multiplicity of options can be accessed simultaneously and exploited to reduce uncertainty.

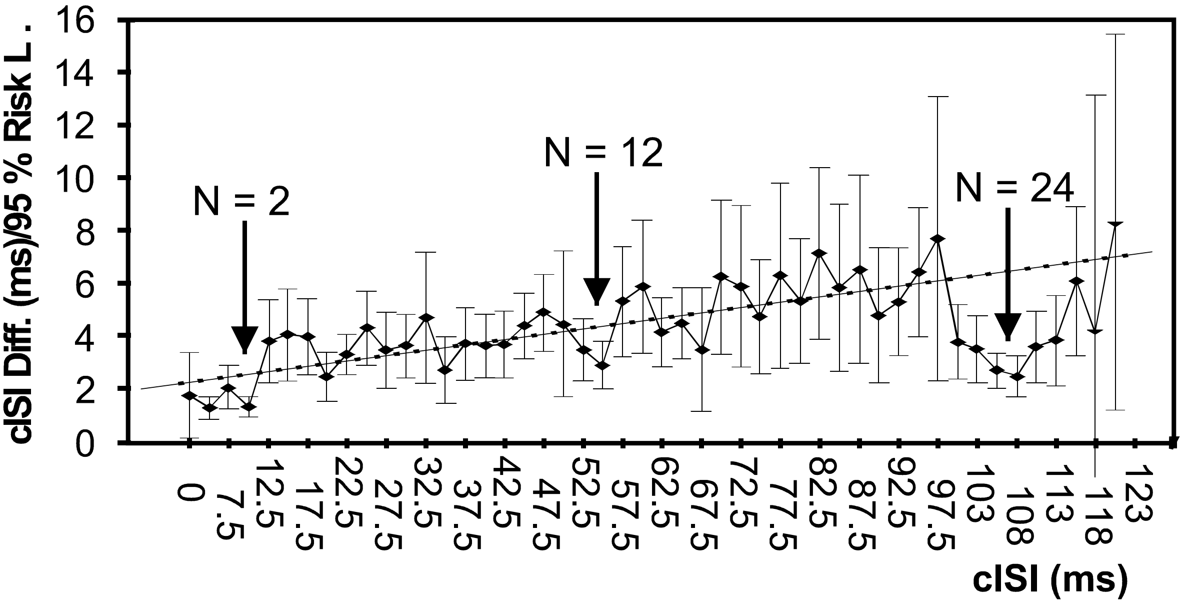

Fig. 5. Linear trend of variability of cISI in beta motion (after Kompass, 2001). Variability is strongly reduced in the vicinity of the most the most prominent multiples 2, 12 and 24.

What has been said is the beginning of another longer story that cannot be told here. Once there is a minimum consensus on their existence, fundamental constants happen to gain a life of their own. Suddenly longstanding unresolved problems and old controversies appear in a new light, and new solutions are coming into view. Let me put it as Fechner's paradox: Psychophysics cannot find its unity unless it addresses its questions in permanent conceptual reference to the physical basis of mind, which not only, but to a large extent, is the brain. However, the brain on which the story goes is a construct of psychophysical theory, not the system described in physiologic, anatomic, biochemical, etc. terms. It has been and it is psychophysical knowledge that assists in locating the equivalents of mental activity in this biological ensemble and not the other way round. I word by word subscribe to Uttal's criticism of neuroreductionism as presented to the 1996 conference. It seems to me that constants theorizing can be based on are a key part of a constructive response.

References

Békésy, G. von (1936). On thresholds for hearing and feeling of sinusoidal low-frequency air pressure oscillations (in German). *Annalen der Physik*, 26, 5, 554-556.

Bredenkamp, J. (1993). Connection of various invariance hypotheses in psychological memory research (in German). *Z. f.. exp. u. angew. Psychol.*, 40, 368-385.

Bredenkamp, J. (2003). Cavanghs hypothesis within the context of other invariance hypotheses. In: Kaernbach, Chr., Schröger, E., & Müller, H. (Eds.), *Psychophysics beyond Sensation*, 319-329. Mahwah: Erlbaum

Brecher, G. A. (1933). The emergence and biological significance of the subjective unit of time—the moment (in German). Zeitschrift für vergleichende Physiologie, 18, 204-243.

Burle, B., Macar, F., & Bonnet, M. (2003). Behavioral and electrophysiological oscillations in information processing: A tentative synthesis. In: Helfrich, H. (Ed.), *Time and Mind. Information Processing Perspectives*, Chapter 12, 209-232. Göttingen: Hogrefe & Huber.

Geissler, H.-G. (1985). Sources of seeming redundancy in temporally quantized information processing. In G. d'Ydewalle (Ed.), *Cognitive information processing and motivation*. 23rd Intern. Congr. of Psychol., 3, 119-228. Amsterdam: North-Holland.

Geissler, H.-G. (1987). The temporal architecture of central information processing: Evidence for a tentative time-quantum model. *Psychological Research* 49, 99-106.
Geissler, H.-G. (1992). New magic numbers in mental activity: On a taxonomic system for critical time periods. In Geissler, H.-G., Link, S. W. and J. T. Townsend (Eds.): *Cognition, Information Processing and Psychophysics*, 293-321. Hillsdale: Erlbaum
Geissler, H.-G., Schebera, F.-U., & Kompass, R. (1999). Ultra-precise Quantal Timing: Evidence from Simultaneity Thresholds in Long-Range Apparent Movement. *Perception & Psychophysics*, 61, 707-726.
Geissler, H.-G., & Kompass, R. (2003). Invariants in Mental Timing. In: H. Helfrich (Ed.), *Time and Mind II*, 185-208. Göttingen: Hogrefe.
Gibbon, J. (1977). Scalar expectancy theory and Weber's Law in animal timing. *Psychological Review*, 84, 279-325.
Kolers, P.A. (1972). Aspects of motion perception. Pergamon Press, Oxford, New York, Toronto, Sydney, Braunschweig.
Kompass, R. (2004). Universal temporal structures in human information processing: A neural principle and psychophysical evidence. In: Kaernbach, Chr., Schröger, E., & Müller, H. (Eds.), *Psychophysics beyond Sensation*, 451-479. Mahwah: Erlbaum
Kristofferson, A. B. (1990). Timing mechanisms and the threshold for duration. In Geissler, H.-G. (Ed.), *Psychophysical Explorations of Mental Structures,* 269-277. Toronto: Hogrefe & Huber.
Lachmann, Th. & Geissler, H.-G. (2003). Search instead of comparison? Representation-guided inference in same-different performance. *Acta Psychologica*, 111, 283-307.
Laming, D.L. (1997). *The Measurement of Sensation*. Oxford: Oxford University Press.
Lebedev, A. N. and Lutzky, M. (1972). Calculation of regularities in visual perception from EEG frequency characteristics (in Russian). Studies of the Research Institute of Industrial Design (*VNIITE*), 4th edition, 95-131, Moscow: Publishing House VNIITE.
Lebedev, A. N. (1990). Cyclic neural codes of human memory and some qualitative regularities in experimental psychology. In Geissler, H.-G. (Ed.), *Psychophysical Explorations of Mental Structures*, 303-310. Göttingen/Toronto: Hogrefe & Huber.
Lebedev, A. N. (2001). The oscillatory mechanisms of memory. *Cognitive Processing, International Quarterly of Cognitive Science*, 2 (2001), 57-65.
Link, S. W. (1992). The Wave Theory of Difference and Similarity. Hillsdale: Erlbaum
Sternberg, S. (1966). High-speed scanning in human memory. *Science*, 153, 652-654.
Sternberg, S. (1967a). Two operations in character recognition: Some evidence from reaction-time measurements. *Perception & Psychophysics, 2,* 45-53.
Sternberg, S. (1967b). Scanning a persisting visual image versus a memorized list. *Annual Meeting of the Eastern Psychological Association*, Boston.
Teghtsoonian, R. (1971): On the exponents in Stevens' law and on the constant in Ekman's law. *Psychological Review*, 78, 71–80
Teghtsoonian, R. & Teghtsoonian, M. (1997). Range of acceptable stimulus intensities: An estimator of dynamic range for intensive perceptual continua. *Perception & Psychophysics*, 59 (5), 721-728.
Treisman, M., Faulkner, A., Naish, P.L.N. & Brogan, D. (1990). The internal clock: Evidence for a temporal oscillator underlying time perception with some estimates of its characteristic frequency. *Perception*, 19, 705-743.
Wundt, W. (1921). *Erlebtes und Erkanntes,* 304, 2nd Edition, Stuttgart: Kröner-Verlag.
Vanagas, V., Balkelite, O., Bartusjavicus, E., & Kirvialis, D. (1976). The quantum character of the recognition process in the visual analysator of humans (in Russian). In Gleser, V.D. (Ed.), *Information Processing in the Visual System*, 26-30. Leningrad: Academy of Sciences of the USSR.