

## **Chapter 3:**

### **How prospective time shapes behavior**

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The famous Kantian a-priories of space and time (1781; 1975) have in common that they constrain and sometimes even determine human behavior but are rarely experienced consciously. The geometry of the perceived world not only allows us to identify objects and their spatial relations to each other but it also determines the position of the perceiver towards the perceived objects. Apparently, for the perceiver it does not constitute a problem that the geometry of the „objects as they are“ differs from the geometry of the „objects as seen from a specific perspective“ (Zimmer, 1995). Actually the complementarity of these geometries determines the properties of the perceived world. Only under rare circumstances the disparity of these geometries is realized, for instance in the Ames-room or when perceiving the world in a camera obscura (Pirenne, 1970). In the case of time the situation is similar: The most direct perception of time happens in the experience of „time gaps“ (Reed, 1972), where suddenly an ongoing action becomes conscious and one realizes that for a period of time this action has been performed without the experience of elapsing time, an everyday experience. For instance, one is driving a car through a well known environment when suddenly an unexpected change occurs and one wonders how one has come to this location. Furthermore, similarly as in space perception the experience of time consists of two distinct metrics: the metric of continuous time which is the same for all possible events, and the metric of episodes which is defined only for the episodes in question and therefore is discontinuous.

The first attempt to unravel the complexities arising from the fact that perceived time differs from the conceptual time of physics, was Kant's distinction of the „concept of time“ and the direct experience of time („the image of time“) which he assumed as coupled by the cognitive process of the „schema“. Postulating this schema, however, does not resolve the problems of different metrics in time. A further problem which is also not resolved is the problem of defining time because time is meas-

ured via the amount of uniform actions (e.g. the movements of the escapement and the pendulum in mechanical clocks or the number of drops in a clepsydra). On the other hand, these actions and their uniformity are characterized by the fact that they need equal time. This together with the dual metric of perceived time motivates the researcher to approach the problem of perceived times directly by analyzing actions in time. Actions happen to be early, to be late or exactly at the right time, they may be hasty or to slow, and they may be accelerating or slowing. In order to experience these properties of actions it is necessary that these actions are perceived „as they are“, that is, with their own characteristic metric, and simultaneously as mapped upon a continuous stream of time, that is, comparable to the metric of the uniform time.

The relations between the experience of time, how subjective duration is determined by the on-going activity, has been analyzed by Henri Bergson in his Oxford lecture on change in 1911. He explicitly assumes that change is constituted of elementary units below which no change happens; that is in line with the assumption of elementary actions constituting what is experienced as time: „*We have to assume that any change and movement is absolutely indivisible.* Let us start with a movement. My hand is at position A and I move it to position B running through distance AB. I postulate that this movement from A to B is something essentially simple. We can undoubtedly say that it is possible to stop our hand during the movement from A to B, but then it would be no longer the same movement. Neither internally with our muscular sensations nor externally with our vision would we have the same perception“ (p. 158 italics in the original, translation by the author) and „*There is change but below change there are no changing objects*“ (p. 163, italics in the original, translation by the author).

The indivisibility of change and the fact that actions taking different amounts of time are equally ‘essentially simple’ imply that subjective time is not a function of ‘objective time’ but of actions. If the units of action were identical for all humans, subjective time would no longer be relative as postulated by Kant in his „Critique of Pure Reason“ (1781; 1975). Bergson states: „...it would not imply that it is necessary to transcend time in order to avoid Zenon’s paradoxa and to free our perception from the relativity as postulated by Kant ... to distance us from change (...), on the contrary it would be necessary again to perceive change and duration in their original changeability“ (1960, p. 157, translation by the author).

Starting with Donders (1869) in the last century, the approach of chronometric analysis of cognitive processes has attempted to resolve



exactly these problems by mapping actions directly upon the physically measured time. The underlying assumption of this approach is that mental processes consist of elementary processes which are uniform concerning their temporal characteristic, an often used analogon for this kind of model are neuronal sequences of different length. The more complex actions necessitate the activities of more levels which are linked by longer sequences of nerves. If this analogue holds, the differences in reaction times mirror the differences in the complexity of the underlying organization for the action. Behind this „strong“ model of chronometric analysis lie assumptions about the structure of the brain as carrier or locus of cognitive processes, namely, the assumption of a strict and decomposable hierarchy (see Sternberg, 1969).

However, starting with the analyses by McCulloch & Pitts (1943) or Hebb (1949) it has become evident that at least locally there are no hierarchical and serial, but netlike parallel and distributed organizations (McClelland et al., 1986). The „strong“ model can only be saved if these parallel processes are confined to modules and if these modules are hierarchically ordered (Fodor & Pylyshyn, 1988). The investigations by Mishkin & Ungerleider (1982) about the separability of space and object perception seemed to support this assumption. However, more recent investigations by Goodale & Milner (1992) indicate that these modules are working in parallel and usually form distributed networks but not hierarchies.

Instead of the untenable „strong“ model of chronometric analysis a more „weak“ alternative seems possible according to which the temporal characteristics of planning reveal if the intended actions are represented as units (modules) or as heterogeneous complexes. Such an approach offers a tentative solution for the problem of the relation between actions and subjective time: the subjective time for an action is equivalent to the set of constituting units. In this model the complexity of an action is not defined via physical time because measuring the reaction times simply serves as an indicator for the unity or complexity of the representations of the intended actions.

It is not necessary to assume that the unitary quality of a representation is static because processes of learning reveal that very complex trains of actions might be represented as a single unit for the expert. If something is represented as such a unit, partial processes which might have been independent or unitary in the beginning of the learning can no longer be addressed directly (see e.g. Zimmer, 1990; Zimmer & Kördle, 1988).

The question concerning the temporal structure of motor actions must be supplemented by the question about the natural unit of motor behavior. This question provides two opposite answers. On the one hand, the opinion of Bernstein and the Gestalt-psychologists, which states that 'natural motor units' exist, and are reflected in the principles of self-organization (for a historical and thematic connection between Bernstein and the Berliner School of Gestalt-Psychology, see Körndle & Zimmer, 1994). Contrary to this opinion are the association psychological or behaviorist concepts based on the idea proposed by Adams (1971) and also, even though not as obviously represented by Schmidt (1975) and Shapiro & Schmidt (1982). According to this view, the complexity of motor actions or programs depends on the amount of simple actions, voluntarily controlled.

Following this comparison, it appears paradoxical at first glance that Adams (1971) refers directly to Bernstein. The precise analysis of the concrete experiments of Adams (1971) and also of Schmidt (1975) show, however, that despite the systems-oriented view of the open loop-theory and the schema-theory of Schmidt (1975), the choice of pointing or position tasks restricts actions to those, which are mechanical and therefore do not show self-organization processes for non-linear systems.

The 'natural motor units' need not be considered as inborn, but rather as a result of the interaction between the organism and its environment. Therefore learning processes can be assumed, which are implicitly and adaptively controlled by the general setting of the organism and environment and not necessarily by an explicitly defined aim. One can assume that - and this has been shown in the studies by Kelso (1990) - that such processes are best characterized as synergetic self-organization processes (see Haken, 1991). The central question is not which theoretical description best fits the facts, but rather are the basic conditions for self-organization processes given. That is, after an adaptive development only one or a few parameters control the emerged motor unit, while considerably less complex constituents of these motor units depend on the same number or even more parameters. As the results on imagining motor reacts - in this case the production of a script (Zimmer, 1982) - indicate the individual motor performances are not sufficiently defined by pictorial - static or dynamic - representations but additionally the kinesthetic and dynamic representation works as an effective cue for the memory of motor acts.

In the dynamic organization of motor units, segments can be found, which are clearly separated by singularities, e.g. change of direction, reduction in speed to zero etc. If one would assume that motor units are



represented as lists of those segments (e.g., it is implied in the program theory) then those segments would have to be faster and more precise than the whole movement. If however one would assume that in the internal representation the motor unit is primary and is defined by only one or few degrees of freedom, then the motor unit should be initialized as fast, if not even faster than the segments of it.

The process of the evolution of motor units has undoubtedly something in common with the concept of overlearning, where - at least according to the behaviorist tradition - the effects are assumed as purely additive and not self-organized. However, since the phenomena of overlearning refer to the whole motor units as well as to the separate segments of these motor units, it would only be relevant for the problem of the characteristics of motor units if there is a dissociation in overlearning between the explicit acquisition of the whole movement and the implicit acquisition of the partial movements.

Seemingly, a connection can be constructed between the motor theory of Adams (1973) with its central processes of 'timing' and 'sequencing' and Kien's notion of characteristic time structures (see e.g. Schleidt & Kien, 1994). Schleidt & Kien and partially Pöppel (1990) assume that the necessary time for tasks of a specific complexity is independent from the number of activated motor constituents as defined physiologically, but depends on the number of action units. In contrast, the concepts of Adams (1971) or Schmidt (1975) imply that this time correlates with the *number of the separate components (i.e., parameters to be set) or in the* case of established schemata with the time between the start signal and the beginning of the motor unit. This time is described in the literature as preparation time (for the bio-psychological fundamentals see Requin, 1980; Brunia et al., 1985). The study of Sternberg et al. (1978) and the new experiments of Kornbrot (1989; 1991) apparently confirm the position according to which complex actions require longer preparation times.

A traditional approach to the identification of such motor units is the chronometric analysis (Sternberg, 1969). The preparation times for sequences of motor actions should become longer the more complex the sequence of motor actions is. For instance, it should take longer to react after the „start“-signal if one has to type a word consisting of five letters than if a word contains two letters. This effect would be independent from perceptual processes because the subjects know in advance which word is coupled with which signal. It becomes apparent that independent from the number of actions to be executed, the level of cognitive processing remains the same (see Figure 1, p. 51), namely, the skill level

(Rasmussen, 1986). Operations on the rule or knowledge level are not necessary to perform these tasks.

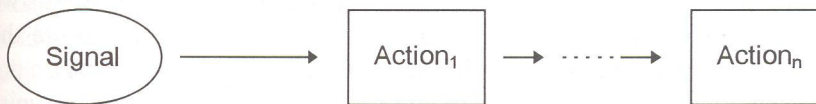
The increase in reaction times is explained in the framework of information processing. Namely, the preparation of any motor action takes a constant time and these preparation times combine; in this case the additive factor method (Sanders, 1980) can be applied to the analysis of motor behavior. The identification of motor units is possible if tasks are found in which there is a linear increase of reaction times depending on an increase in complexity. Sternberg et al. (1978) have been the first to apply this theoretical principle to motor actions in speaking (see also Gracco, 1990). Further investigations, for instance, of tapping (Canic & Franks, 1989), typing (Gentner, 1987; Kornbrot, 1989), or grasping (Green, 1982), have lead to interpretable results. However, the attempt to identify the motor units in writing has given rise to contradictory results. The data of some experiments support the information processing model by showing a linear, albeit slight, increase of reaction times with an increase in the number of letters, in most experiments. However, no increase whatsoever has been found (see Hulstijn et al., 1983). The analysis of the different complexity of letters equally fails to produce consistent results in line with the assumption of information processing.

If letters or numerals were unitary actions, it should take longer to initialize writing the longer the sequence of symbols in the task is. If, however, the units of actions are lines, circles or segments of circles as Gibson & Levin (1975) suggest, the number of these constituents of letters should determine the preparation time. Neither assumption about the representation of handwritten symbols seems to hold because, as already said, in most experiments on handwriting one finds no differences in preparation times depending on the number or complexity of symbols in handwriting. The question arises why is handwriting so as compared to typing, pushing buttons, or speaking.



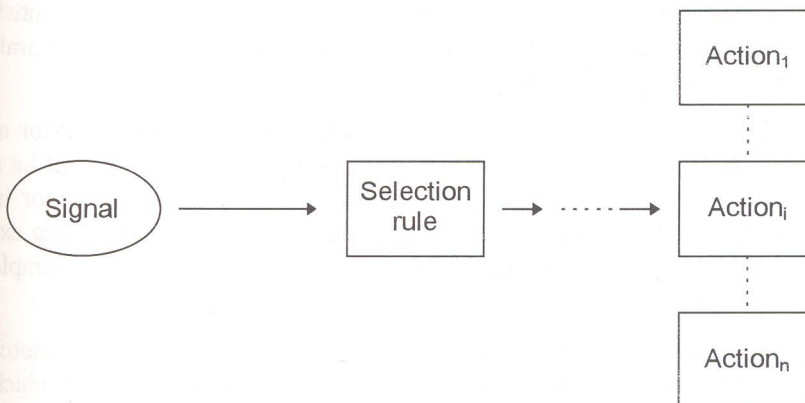
Skill-based level:

One signal corresponding to one motor action



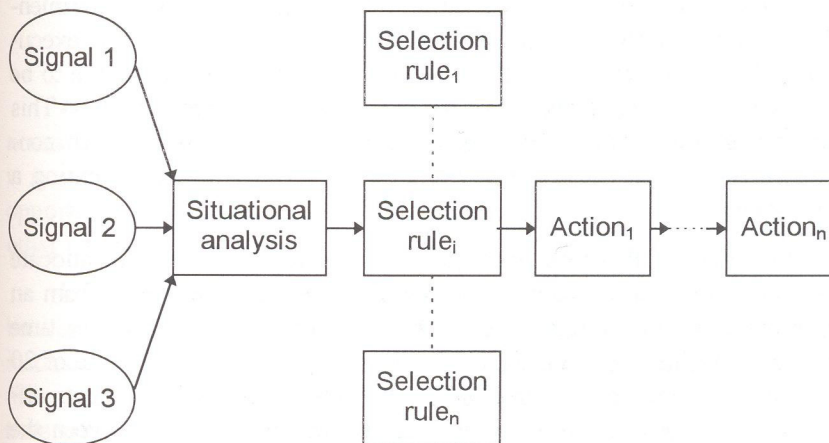
Rule-based level:

One signal initiates a rule for the selection of a motor action



Knowledge-based level:

One or more signals indicate that the execution of one or more (not specified) motor actions is necessary



**Figure 1:** Levels of processing in the selection of actions (after Rasmussen, 1986)

One possible cause for these differences might be that subjects allocate their time in writing differently: Some, „the information processing“ subjects, take their time in planning, that is, more time is expended as we increase the complexity or number of symbols. Also, they execute the task ballistically, that is, when having started to write the subjects do not need to control or plan ahead anymore. Other subjects, the „opportunistic planners“, start the task immediately, that is, they do not show a latency which lengthens the more actions in the motor buffer have to be brought in sequence. However, when executing the task the time per letter increases proportionally with the number of letters to be executed, that is, the rate effect mirrors the amount of advanced planning in parallel to the execution of writing (Carcia-Colera & Semjen, 1988).

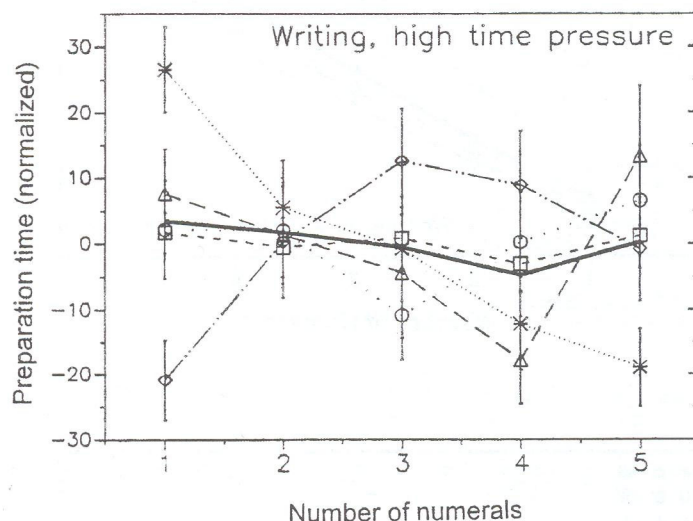
This has led to the question, what distinguishes motor behavior in writing from other repetitive motor actions. One possibility would be a different structural organization (as compared to a motor behavior in speaking). Another reason might be that different methods of writing exist and therefore averaging data over subjects does not result in a simple linear model.

Experiments about the time course in planning and executing motor actions point to two different directions: (i) There are experiments which - albeit under very restrictive conditions - support the notion of preparation times relative to the number and/or complexity of consecutive actions. The latency effect is explained by a search in the motor buffer which takes longer the more elements are in it and a „ballistical“ execution of motor actions after terminating this search. (ii) Other experimental data do not show this kind of latency but a „rate effect“ in the execution of the motor actions, that is, the more motor actions that have to be executed, the longer it takes to execute every single motor action. This can be explained by a process of opportunistic planning in which consecutive motor actions and monitoring the sequence while executing a motor action.

In order to illustrate how qualitatively different subjects allocate their time in preparing to act, data for five subjects are shown from an experiment where subjects had to write up to 5 numerals under time pressure (Figure 2, p. 53). Each data point represents the average of 20 reaction times. Not only that in an analysis of variance the subjects differ significantly, but there is also a significant interaction between the subjects and the number of numerals to be written; that is, subjects follow qualitatively different allocation strategies depending on the task at hand. Subject „BS“, for instance, becomes faster the more ciphers have to be written down, subject „PM“ shows a flat curve, and subject „AS“



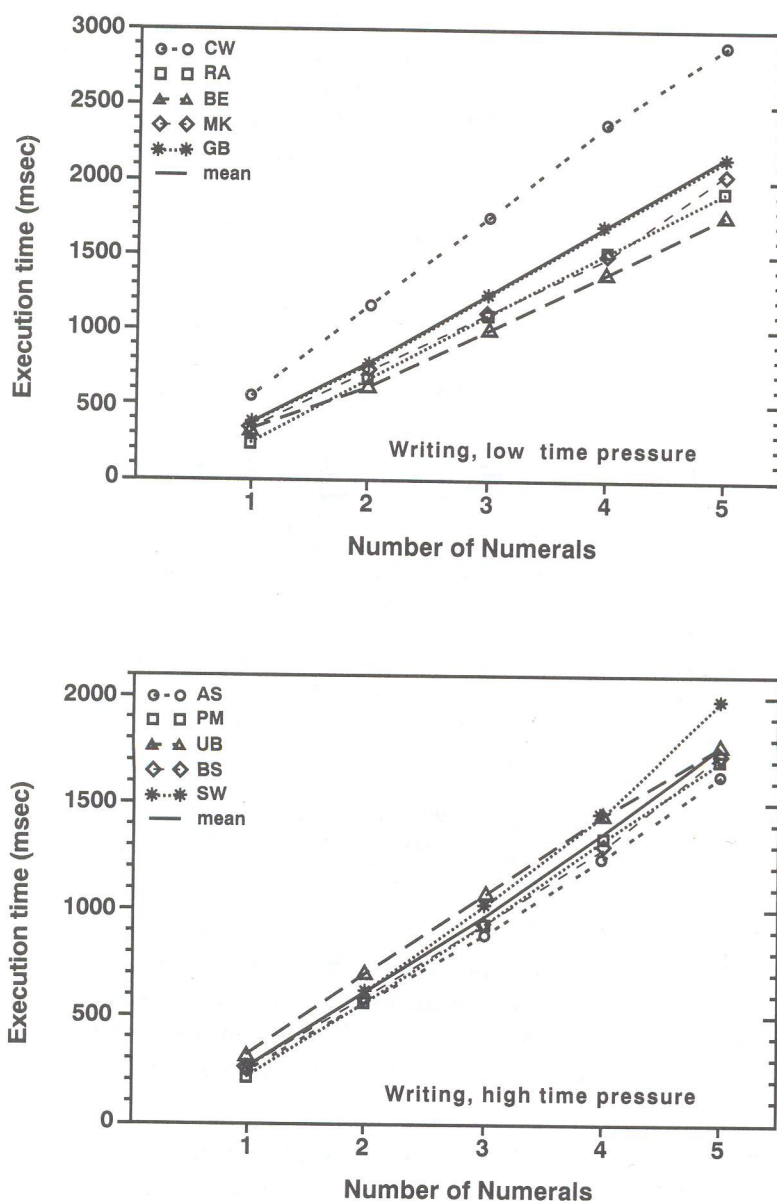
shows the expected increase for the first three letters but then the curve declines again. Different allocation times in writing do not have an influence on the execution times as shown in Figure 3 (p. 54) where the quadratic form of the curve shows that the rate effect and the data for all subjects are practically identical.



**Figure 2:** Normalized preparation times for subjects SM (O), AK (□), PS (Δ), RF (◇), RW (\*). The bold line indicates the averages and the bars the standard deviations.

A repetition of these experiments where subjects did not have to react as fast as possible, reveals that the quadratic form in Figure 3 (p. 54) is not coincidental but that subjects in writing really allocate their time opportunistically. In parallel to executing one letter they plan already the other letters: the rate effect.

In conclusion, the strong differences in the chronometric analysis between tasks which all increase with the number of required actions and instructions (*with* versus *without* time pressure) indicate that in regard to motor actions humans do not have an internal clock, that is, for them time is not defined independently from the task and the situation.



**Figure 3:** The execution times for writing 1 - 5 numerals. The trend is significantly quadratic for the average time as well as for 3 out of 5 subjects

A special case for this differential allocation of time is music where Grepmaier & Zimmer (in preparation) have investigated if experts and



novices in music (expert versus lay musicians) have different frames of reference for musical tempi. The surprising result is that amateur musicians are much more consistent in calibrating the musical tempi to beats on the metronome than experts. Professional pianists only when playing simple parts of a sonatina by Clementi (op. 36 Nr. 1 „allegro“, see Figure 4, p. 54) used a tempo as defined by metronome beats. However, a closer analysis of more complex parts reveals that some musicians slow down immediately before the complex parts but execute these according to the „objective“ tempo, while others slow down the execution of the complex part, that is, they use the technique of „rubato.“

M. Clementi, Op. 36 Nr. 1  
(1752-1832)

**Allegro**  
A 1

The image shows the musical notation for the first movement of M. Clementi's Op. 36 No. 1, 'Allegro'. The score is in G major, 3/4 time, and consists of five systems of piano and bass staves. The first system is marked 'A 1' and 'Allegro'. The second system is marked 'II'. The third system is marked 'B 2'. The fourth system is marked 'A 1'. The notation includes various musical symbols such as notes, rests, accidentals, and dynamic markings like 'f' and 'p'.

**Figure 4:** Notation of the sonatine by M. Clementi, Op. 36 Nr. 1

As Crossley-Holland (1980, p. 745) remarks: „Such modifications of tempo, known as *tempo rubato* - i.e., ‘robbed time’ - are part of the music’s character. Rubato needs the framework of an inflexible beat from which it can depart and to which it must return.“

For the listener, the two different techniques give rise to different impressions of tempo: in the first case a variation in tempo is experienced, namely, an increase of tempo in the complex parts. In the second case, the tempo is perceived as remaining equal for the entire piece. If one draws analogies to the perception of space, these experiences of time become very plausible, because in the perception of distances one observes the „clutter“ effect, that is, the more discriminable objects lie between two distinct points the longer this distance is perceived, as apparent in the Oppel-Hering illusion. In time perception this implies that a constant ratio of frequency and or complexity of events to time constitutes the frame of reference, deviations of this ratio from a constant value give rise to the impression of variability in the flow of time.

From the theoretical considerations as well as from the experimental results the following tentative conclusion concerning the relation between action and perceived time seems plausible. Not only does the prospective time, that is, the time budget, shape future actions but the intrinsic structure of these actions also shapes the perceived time course. A unitary but complex action consisting of many constituents arranged in an intricate manner is experienced as shorter in time than a sequence of many simple actions, even if the overall number of constituents is the same.

Gerardo Dottori, a futuristic painter has depicted the complex texture of time and action in his painting ‘speed’ of 1925 (see Figure 5). Perhaps this picture captures best what is implied in the psychological aspect of time.

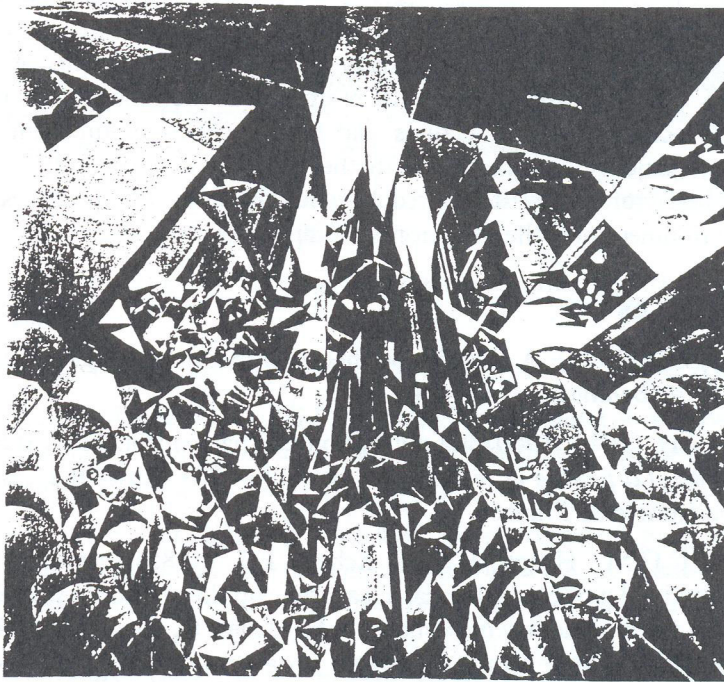
## Summary

The perspective of research on the perception of time is usually retrospective,<sup>1</sup> that is, a sequence of actions is performed or a sequence of events is observed and afterwards the amount of elapsed time is estimated or the experience of elapsed time is recalled. These estimates and recollections usually correlate with the complexity or density of the sequence of events in time.

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<sup>1</sup> However, see Block & Zakay, this volume, chapter 9.





**Figure 5:** Gerardo Dottori (1925) *Velocità, (tre tempi). Partenza*

As a starting point of our investigations we have switched the perspective from retrospective to prospective, that is, how do the expectations about actions to be done influence our allocation of time. Time in this context is regarded as a scarce commodity which is spent cautiously and in relation to the complexity of the task at hand.

Different fields of action have been investigated: (i) writing signs, (ii) uttering words, and (iii) producing melodies, all on differing levels of complexity. In order to cope with this complexity two different strategies in allocating time are possible: (i) *the allocation of a complexity-dependent amount of time before starting* the entire sequence of actions. That is, reserving so much time after receiving the starting information that all relevant representations of motor actions can be activated and brought into the correct sequence with the subsequent motor activity in ballistic form, or (ii) *the quasi-opportunistic allocation of time* immediately before the single actions combined with a critical slowing down during parts of higher complexity.

The data of individual subjects reveal that they resolutely adhere to their - idiosyncratic - strategy of allocating time and only rarely do clear cut cases of strategy (i) occur. Mostly subjects exhibit variants of strategy (ii). Finally, experiments with more global motor behavior reveal that the actual timing of actions and the allocation of time aim at a smooth, „unjerk“ interaction with the physical environment. „Jerk“ motor behavior seems to occur only when there are abrupt changes in the environment or if the behavior is entrapped in a singularity.

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