AVAILABILITY AND ACCESSIBILITY OF INFORMATION IN PERCEPTION OF MOVING STIMULI

KAIRI KREEGIPUU

Department of Psychology, University of Tartu, Tartu, Estonia

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CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This dissertation is based on the following original publications, further referred to by their respective Roman numerals.

I   **Kreegipuu, K.** & Runeson, S. (1999). Becoming competent through the perceiver's eye. In *Studies in perception and action V* (M.A. Grealy & J.A. Thomson, Eds.), pp. 20–23. New Jersey: Lawrence Erlbaum Associates, Inc.

II   Allik, J. & **Kreegipuu, K.** (1998). Multiple visual latency. *Psychological Science, 9*, 135–138.

III **Kreegipuu, K.**, & Allik, J. (2003). Perceived onset time and position of a moving stimulus. *Vision Research, 43,* 1625–1635.

IV   **Kreegipuu, K.**, & Allik, J. (in press). Confusion of space and time in the flash-lag effect. *Perception*

V   Allik, J. & **Kreegipuu, K.** Detection of motion onset and offset: Reaction time and visual evoked potential analysis. (submitted)

INTRODUCTION

It is perhaps impossible or at least very difficult to overestimate the importance of motion perception for most living organisms. Everyone can easily imagine situations where moving stimuli carry a potentially threatening message. Running predators, driving cars and flying objects are only some of them. Motion perception is important not only for survival but also for everyday activities and fun. Motion is one of the most efficient depth or grouping cues and moving objects are more likely to catch one's attention (or do so more quickly) than the same objects when they are stationary.

There are hundreds of tasks that human beings can solve with the aid of a visual motion perception system.[1] Traditional motion perception tasks are velocity and direction discrimination and motion detection. In addition to the usual tasks, motion analysing system provides information[2] for several other systems and so helps either directly or indirectly to solve a great number of perceptual problems. For example, one of the most firmly established empirical laws for all sensory systems is that the response time increases with the stimulus intensity. However, for the movement analysing system the intensity-dependent time differences in stimulus processing almost disappear (**Study II**) although they are crucial in many other situations. Also temporal and spatial discrimination thresholds diminish considerably due to visual movement impression (e.g., Allik & Pulver, 1994; Exner, 1875; Legge & Campbell, 1981; Palmer, 1986; **Study II**; Westheimer, 1979). At the same time, several famous illusions like the Fröhlich effect (Fröhlich, 1923), the flash-lag effect (Nijhawan, 1994), the onset-repulsion effect (Thornton, 2002), the representational momentum (Freyd & Finke, 1984) or Pulfrich effect (Pulfrich, 1922) demonstrate that visual motion influences the apparent spatial or temporal position of the moving stimulus. Even more, motion can change the apparent location of a distant stimulus (Whitney & Cavanagh, 2000; 2002). A very interesting perspective of motion perception has been discovered within the ecological psychology. There appears to be a lot of information, even about hidden qualities like dynamic forces or intentions that actors possibly have, available for our perceptual systems within the kinematics of the motion pattern (e.g., Bassili, 1976; Cutting, 1978; Gilden & Proffitt, 1989; Heider & Simmel, 1944; Johansson, 1973; Runeson & Frykholm, 1981; 1983; Runeson & Vedeler, 1993). Thus, visual motion carries information not only about kinematic but dynamic and causal properties as well.

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[1] The term *visual motion perception system* is not physiologically specified here. It has a very wide meaning referring just to any set of psychological operations executed on the output of low-level motion sensitive units.

[2] Information is also treated quite loosely with its meaning ranging from *input to some process* (i.e., close to *idea* or *representation*) to *meaningful structure* (Gibson, 1986).

Do all these perceptual applications of motion information have anything in common? The central message of the thesis claims that they do. There seem to exist several different modes of motion perception that possibly access different aspects of the available representation of motion (cf., Allik, 1999).

What is motion perception?

Definition of motion seems to be trivial — something just changes its position over time. Although this definition of motion is natural for a physicist, it was not enough so for Mother Nature who has built the motion analysing system from neurons and connections between them. It turned out that the neural network sensitive to motion signals the presence of motion even if nothing has objectively changed its position (e.g., Adelson & Bergen, 1985; Burr, Ross & Morrone, 1986; van Santen & Sperling, 1985; Watson & Ahumada, 1985). Since Sigmund Exner (1875) it has been known that a very short temporal asynchrony between luminance excursions at two neighbouring locations is enough for a creation of a vivid movement impression. The study of movement perception started from the specification of necessary and required spatio-temporal conditions for the eliciting a "good" motion impression (e.g., Korte, 1915) and continued with the search for the sampled motion that appears indistinguishable from the continuous motion (Morgan, 1980; Burr et al., 1986).

It is very tempting to think about the apprehension of the motion-related information as having the only or the main constraint in the physiology of the low-level functional units or physical energy that give rise to a representation[3] of perceived event. Still it is very easy to show, with reference to top-down illusions for example, that this is not true. Events may give rise to more than one representation (cf., *Multiple Drafts Model*, Dennett & Kinsbourne, 1997) and perceptual system can surpass borders between its separate domains of vision, hearing, touch, taste and smell (e.g., McGurk & MacDonald, 1976; Stoffregen & Bardy, 2001)[4]. The latter may just mean that information is available to a larger number of subsystems, not necessarily more available

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[3]   *Representation* has a quite abstract meaning here. It is related to the sensory input, includes some unknown processing of it, and at least an aspect of it ends in the pheno-menal awareness.

[4]   There is another aspect that is related to the representation and deserves some attention. The terms *different representation* and *different access to the representation* will be used intermittently throughout the text. It is not incidental mistake but mirrors exactly how they are considered — as semantic synonyms. This is in a good agreement with the idea of multiple drafts of experience in perception (Dennet & Kinsbourne, 1997) that are formed in a parallel stream, can be revised at a great rate, and no one is more correct than another. It also resonates with the encoding specificity idea familiar from memory research (Tulving & Thomson, 1973, see also later).

information (Runeson, Jacobs, Anderson & Kreegipuu, 2001). The fact that similar effects can be found cross-modally (for FLE see Alais & Burr, 2003 or Krekelberg, 2003 but also Hine, White & Chappell, 2003) might refer to the non-perceptual nature of the effect (i.e., due to deliberate computation or to a common underlying principle in the functioning of the nervous system etc.).

The idea that subjective experience is not firmly determined by low-level sensory input or simple physical energy has been often overlooked in the study of motion perception. Theoretically, the basis for recognizing the variability of experience arising in one and the same physical situation has long been available, at least since the middle of the 20th century when James Gibson came up with his theory of ecological perception. There he redefined perception as an active "experiencing of things rather than a having of experiences" (1986, p. 239) and senses as "perceptual systems" (1966). These perceptual systems are built for picking up structural properties in the ambient array of light, not just physic energy. With continuous elaboration of activity perceptual systems become attuned to more and more subtle, elaborate and precise aspects in the stimulus flow. Consequently, variability in perceptual experiences is inevitable. One possible reason for ignoring the variability in perceiving moving stimuli is the fact that the research community rather reluctantly accepted Exner's (1875) innovative notion that motion perception is one of the basic perceptual qualities and not derivative of the perception of space and time.

Two stages of computations in motion perception

It is possible to talk about the distinction between movement encoding and decisions about kinematic properties of the visual scene (Dzhafarov, Sekuler, & Allik, 1993). According to the proposed distinction, motion encoding is a general task-independent computation providing a sufficiently rich internal representation of the kinematic properties of the visual scene. This representation is achieved by a mass-action of the elementary motion encoders. The output of the encoding system is fed into the task-specific detection system that enables to answer more specific questions about the nature and properties of the motion. Such questions include, among others, "Has the target moved at all?" and "Has it changed its speed and direction?" The special-purpose computation involved is understood as a particular form of weighting summation across the network of visual encoders. The distinction between encoding and decision can explain the disparity between different tasks: the information that is available for one type of computation may not be available for another type of computation. As a general principle it means that not all information available is necessarily accessible when a specific question is asked. Different tasks may rely on different portion of information represented by the network of elementary motion encoders.

This means that the performance in a particular motion-related task cannot be reduced to the properties of the elementary encoding network. It is also erroneous to think that the relatedness to the elementary encoders is stronger and immediate in some "simple" tasks because, as Runeson (1977a) has elegantly shown by his model of a polar planimeter, the determination what task is simple and what task is complex is not obvious. What may be difficult and complex for a physicist may be elementary for the biological system and vice versa. Even more, there is no guarantee the observer is able to solve apparently simple tasks imposed by the experimentator. There may relatively simple tasks for which perceptual system is simply not adapted and the observer, not exactly knowing it, can silently substitute the original task with some other task. This was convincingly demonstrated in a study by Morgan, Hole and Glennerster (1990) who described the influential constraint upon visual perception arising in situations where observers meet perceptual tasks to which they are not adapted for. Such a task was, for example, the "determination of the position of a dot in the presence of surrounding cluster of dots" that was substituted by the "determination of the centre of the same cluster of dots." Thus, there is no reason to believe *a priori* that the logical reconstruction of steps created in the researcher's head are also followed by the visual system. But there is reason to believe in parsimony as a basic principle in the perception that guarantees that "smart" direct-perceptional mechanisms (Runeson, 1977a) will do the work, whenever possible.

Available for perception is not always accessible

The distinction between encoding and decisions refers to the possibility that information generally available for the visual system is not always accessible in a particular mode of retrieval of that information. Thus, the distinction between available and accessible information is relevant also for visual perception (Allik, 1999), not only memory (Tulving & Pearlstone, 1966). Perhaps it is not very surprising because it is impossible to separate perception from memory. As Gibson (1966) has formulated: "It is not possible to separate perceiving from expecting by any line of demarcation" (p. 279). This also means that both are inseparable from memory or learning. If perception operates hand in hand with memory, it would be more natural to expect that the distinction between available and accessible information is valid for all forms of mental representation, not exclusively for memory. Another lines of evidence for the similarity between the operating characteristics in memory and motion perception are priming (Tulving, Schacter & Stark, 1982 *vs* Anstis & Ramachandran, 1987; Blake, Ahlström & Alais, 1999; Pinkus & Pantle, 1997) or as suggested by Allik (1999) the similarity between the recognition failure (Tulving & Thomson, 1973) and identification superiority effect (Allik, Dzhafarov & Rauk, 1982). Naturally, as a consequence of the distinction, the encoding specificity

(Tulving& Thomson, 1973) is expected to be valid, in a slightly adapted form, also for perception: conscious percept is determined by the encoded stimulus representation and perceptual task demands.

However, in some remarkable clinical conditions the dissociation between available and accessible becomes more transparent. A telling example is "blindsight" (Weiskrantz, 1997), meaning a residual vision after the damage of visual cortex (striate cortex or V1), probably due to alternative connections from the lateral geniculate nucleus (LGN) to the cortex. "Blindsight" patients (among whom GY is one of the most famous) show good or very good discrimination ability with simultaneous reports of absence of the awareness of stimuli. Adequate psychophysical or physiological responses without conscious recognition have been repeatedly described (e.g., Kolb & Braun, 1995; Pöppel, Held & Frost, 1973). This illustrates the importance of going beyond the scope of the traditional psychophysical methods. It is really amazing how little attention has been paid to the variation of the response mode while keeping the input and stimulus condition constant. It seems that the research of visual perception has always assumed, implicitly at least, that the result of perception is invariant to the question posed and the mode of answer.

Introspection is certainly a psychological method that despite of its declared uselessness (e.g., Nisbett & Wilson, 1977) really deserves rehabilitation. Not necessarily in Würzburgian form of wordy impressions but in a more structured and immediate form (Ericsson & Simon, 1980). One important factor that influences the quality of introspection seems to be the time lag between the task performance and the introspective or retrospective report about the performance. Generally, the shorter the lag, the more reliable the report (Ericsson & Simon, 1980; Hurlburt & Heavey, 2001) — even concurrent verbalisation is suggested to be preferred over retrospective reports. At the same time the researchers also warn about the possible influence that introspective reports may have on the processes under study. One of the most successful utilisations of introspection in experimental psychology comes from the study of memory, again. Subjects seem to have an ability to distinguish conscious recollection (*"remembering"*) from just knowing (*"knowing"*) that the item has been presented previously (Gardiner, 1988; Tulving, 1985). Thus, researchers have to be careful in applying introspection but it can provide reliable information. Another quite successful use of introspective measures is rating one's confidence (e.g., Juslin & Olsson, 1997; Kreegipuu & Allik, 1999).

Introspective access to modes of apprehension of information in the dynamic event

In **Study I** introspective access to the modes of apprehension of the information that motion pattern of stimuli potentially contains, was tested. Fortunately a task

where two alternative perceiving modes can be revealed was easy to find — the one that judges the relative mass of colliding objects.

In the classical understanding, the information obtained through vision is about "superficial" occurrences: shape, spatial layout, motion, and change. More recent research, deriving from the Gibsonian ecological notion of perceptual information, has shown that we can also become aware of "hidden" or relational aspects by vision. For example, people are able to discriminate which of two colliding objects is heavier (e.g., Gilden & Proffitt, 1989; Runeson, Juslin & Olsson, 2000; Runeson & Vedeler, 1993; Todd & Warren, 1982). Despite a unanimous recognition of people's ability to judge the relative mass of colliding objects, there is considerable disagreement concerning the nature of this remarkable ability. There are two main theoretical approaches in the field: the *direct-perceptual* (invariant-based; Runeson, 1977b; Runeson & Frykholm, 1983; Runeson et al., 2000; Runeson & Vedeler, 1993) and the *inferential* (cue heuristics-based; Gilden, 1991; Gilden & Proffitt, 1989). The first approach relies on the Gibsonian ecological perspective (Gibson, 1966, 1986) and on the principle of *kinematic specification of dynamics* (the KSD-principle; Runeson, 1977b; Runeson & Frykholm, 1983). As Gibsonian and gestalt-psychological logic says, perception is more contingent on stimulation than on thought and memory processes, and perception of mass in the direct-perceptual tradition is construed as having no intermediate steps. The KSD-principle asserts that the relative mass of two colliding objects is uniquely given by the relative motion change of the objects. Thus, people are just able to pick up the invariant dynamic information by vision. The cue-heuristic tradition states, on the contrary, that people have simple rules about the world, and they apply one or a few of the rules to find the solution in each particular case. In the case of judging the relative mass of colliding objects, people just rely on the most salient cue in the motion pattern (such as ricochets or exit speeds), and apply a corresponding pre-conceived rule (e.g., the object that ricochets or has a greater exit speed has to be lighter).

There is evidence that the two distinct modes of apprehension — direct-perceptual or "sensory", "intuitive" and inferential or "cognitive", "intellectual" — do exist (Runeson & Andersson, in press; Runeson et al., 2000; **Study I**). It has even demonstrated that in the relative mass of colliding balls task a transition from the inferential to the direct mode takes place with growing expertise (Jacobs, Michaels, Runeson, 2000; Runeson et al., 2000). Several indicators such as performance characteristics (i.e., specific distribution of solution probability) and/or observer's comments (e.g., confidence ratings or post-experiment debriefing data) have been used to prove the mode transition in skill acquisition. In **Study I** observers classified their experience in the task on trial-to-trial basis providing converging evidence of such transition and the meaningful application of introspection. **Study I** also shows that motion information may be perceived in two different modes and that access to the modes of apprehension is, at least to some extent, reliable.

13

However, the most serious criticism against methods applied in **Study I** goes back to Helmholtz (1925/2001) who considered inferences (or conclusions) that perception does unconscious (i.e., unaccessible to one's mind). However, even if it was normally the case, **Study I** indicates that when precautions are taken researchers can rely on introspective data as well. Here the recipe for the relative success was (1) a good theoretical background of the two alternative modes, (2) well-defined classifications of the two phenomenological alternatives (incl. subjective debriefing data from previous experiments) and (3) immediate and repeated (384 times) asking for introspective reports. In another study (Kreegipuu & Allik, 1999) observers had to discriminate between the left-right direction of apparent motion and their confidence about every single decision they made. Preliminary data from the study indicate that the subjective confidence ratings were even more strongly related to the parameter presumably defining the objective stimulus difficulty (i.e., the stimulus onset asynchrony, SOA, that ranged from 0 to 18 ms) than the solution probability. As the Pearson product moment correlation coefficient for the SOA-confidence ($r=.51$, $n=3600$) was significantly larger ($p<.0001$, *two-sided test*) than for the SOA-accuracy ($r=.31$, $n=3600$), we may conclude that the system assigning confidence labels is even more sensitive to the movement information than the manual response system. This means that in some cases people just feel more than could actually discriminate.

Any evidence that allows one to account introspection for the reliable-enough method should be appreciated because almost all psychology (incl. experimental psychology) relies more or less on introspective data. Even a simple button press in a psychophysical test requires the inner sense and some categorisation. In next studies the distinction between availability and accessibility of information is demonstrated by more conventional psychophysical experiments.

Effect of movement on visual latency

The first more traditional demonstration of the different use of the same stimulus information is related to visual latency (VL). There is at least one basic constraint and one basic rule in perception. The constraint is the velocity of nerve conduction (first measured by Helmholtz in 1850; see Boring, 1957) that means that delays are inevitable in perception. The "stronger stimulus–shorter delay, weaker stimulus–longer delay" is the very basic rule, measured in the field of stimulus intensity already by Exner (1868) and later by Hess (1904). These two facts together and the agreement between psychophysical and physiological measures (Bernard, 1940; Granit, 1947) have provided a dominant belief that the intensity-dependent latency originates in the retina (e.g., Roufs, 1963, 1974) and remains invariant for the whole visual system. Until **Study II** refuted the belief by showing that movement analysing system,

not spatial or temporal closeness of stimuli *per se*, can overcome the intensity-dependent differences in the VL. The perception of a test flash that had a variable luminance (5.6-256 cd/m^2) was studied in the reaction time (RT) and the temporal order judgment (TOJ) task. Spatio-temporal configuration of stimuli and the presentation of a reference flash determined whether the test flash alone, a clear succession or motion of flashes was perceived. Whenever the stimuli evoked the good apparent movement impression, the relative intensity-dependent VL was reduced 2–8 times in the RT or the TOJ task, respectively. Again, it nicely demonstrates the dissociation between available and accessible information: the intensity induced changes in VL are pronounced in one type of visual task but virtually lacking in another task. In **Study II** the movement impression, not spatial or temporal closeness as such, almost completely abolished the intensity-dependent latency differences.

Perceived position and time of moving stimuli

During the past decade, one of the most extensively studied illusions about the mislocalisation of the moving object is the flash-lag effect (FLE). The FLE refers to the situation when in case of spatially perfectly aligned stimuli, a moving and a flashing one, the moving stimulus seems to be shifted into the direction of its movement, and thus lead the flash (Nijhawan, 1994). Although the phenomenon is known for a century and described by several authors (e.g., MacKay, 1958; von Tschish, 1885), it was Nijhawan (1994, 1997) who named it and brought the FLE to the wide audience.

Despite considerable efforts, the explanation of FLE remains elusive. The explanations of the FLE that have been advanced so far can be divided into three general groups: ones that consider *spatial* (e.g., Brenner & Smeets, 2000; Eagleman & Sejnowski, 2000; Krekelberg & Lappe, 1999; 2000; Nijhawan, 1994, 1997), *temporal* (e.g., Kirschfeld & Kammer, 1999; Lappe & Krekelberg, 1998; Nishida & Johnston, 2002; Patel, Ogmen, Bedell, & Sampath, 2000; Purushothaman, Patel; Bedell, & Ogmen, 1998; Schlag & Schlag-Rey, 2002; Whitney & Murakami, 1998; Whitney, Murakami & Cavanagh, 2000) or *"high-level"* mechanisms (e.g., Arnold, Durant & Johnston, 2003; Aschersleben & Müsseler, 1999; Baldo, Kihara, Namba & Klein, 2002; Baldo & Klein, 1995; Baldo & Namba, 2002; Haddad, Carreiro & Baldo, 2002, Kirschfeld & Kammer, 1999; Müsseler & Aschersleben, 1998). The proposed classification is neither exclusive nor even absolutely clear-cut because, for example, attention is playing certain role in some temporal and spatial models (see **Study III**, division 2.1.1.) or the position assigning takes place at a relatively late phase of processing in most spatial models. Beside the three broad classes of explanation, there are some other explanations including low-level mechanisms in the retina (Berry, Brivanlou, Jordan & Meister, 1999) or eye-movements

(Nijhawan, 2001) or non-specific thalamocortical facilitation for stimuli in stream (Bachmann, 1999; Bachmann, Luiga, Põder & Kalev, 2003).

In spite of differences in the theoretical background for the FLE, most researchers use basically the same experimental paradigm. A typical task is to judge whether a moving and a flashed stationary stimulus are spatially aligned or not (e.g., Baldo & Klein, 1995; Kirschfeld & Kammer, 1999; Müsseler, Stork & Kerzel, 2002; Nijhawan, 1994, 2001; Purushothaman et al., 1998; Whitney, Cavanagh & Murakami, 2000). According to the velocity of the moving stimulus, from the adjusted or estimated spatial lag relative processing time for moving and flashed stimuli is usually found. Only few exceptions from the practice are known (Brenner & Smeets, 2000; Eagleman and Sejnowski 2000, 2002, **Study III; IV**). From the perspective of availability and accessibility it is not necessary to assume that the timing or localising of the same visual event — the change of the colour of a moving object, for example — inevitably leads to the same result.

This is exactly what was found in **Study III**. Observers judged in separate blocks the onset time or position of a suddenly appearing bar, either stationary or moving with one of 4 velocities (in the range from 4.2 to 32.7 °/s). In the temporal task the FLE was observed: for the perceived simultaneity a stationary probe flash had to be presented up to 40 ms before the moving test bar (Fig. 2A) although the illusion was rather modest compared with that described in many published studies. At the same time, the position of the movement onset was estimated almost perfectly (Fig. 2C): no reliable mislocalisation or the Fröhlich effect (Fröhlich, 1923) was observed. The greater accuracy of the localisation task was particularly striking if the perceived spatial lags were expressed in terms of expected delays and vice versa. Computationally found delays or lags did not match empirical ones (Fig. 3). So, **Study III** demonstrates that in case of moving stimuli making inferences about temporal processing from spatial tasks and vice versa (i.e., using the constant velocity rule) is not justified enough. The dissociation of temporal and spatial judgement tasks means that they are most probably caused by different information represented in the internal representation of moving object.

Even if there are some doubts whether exactly the same stimulus information was presented in different conditions in **Study III**, then in **Study IV** these doubts were completely removed. The basic idea was extremely simple and inspired by colour-changing paradigm introduced by Moutoussis and Zeki (1997). It was first applied for the study of the FLE by Cai and Schlag (2001). Instead of comparing the momentary position of a moving stimulus with a stationary flash, we presented a moving stimulus which at a certain moment changed its colour. The moment of change had to be adjusted either to be simultaneous or aligned with a reference flash. In this way it was possible to obtain separate estimates of the spatial and temporal offset of the same moving stimulus. Colour-change was an event-marker and the observer was provided an opportunity to adjust the reference to a position where the colour-change

appeared to take place or switch it on at the moment when the colour-change appeared to happen.

In addition to the adjustable parameter (space or time), an irrelevant stimulus parameter (time and space, respectively) also varied in **Study IV**. Technically it means that in spatial adjustment task, for example, the reference flash could appear earlier, simultaneously or later than the colour-change took place. And similarly: in the temporal condition the position where the reference was presented was ahead, exactly aligned or behind (with respect to the movement trajectory) the actual colour-change point. In principle, the spatial position of the reference signal is completely irrelevant when the observer indicates the moment of change. In fact, all observers were unable to ignore the irrelevant dimension of the reference signal: the apparent time of the colour-change was influenced by the position of the reference signal and the apparent location of the colour-change was influenced by the reference signal presentation time. The temporal and spatial attributes of the moving stimulus were confused resulting in beautiful *tau* (Helson & King, 1931) and *kappa* effects (Abe, 1935). Although the subjects were instructed to ignore the irrelevant attribute, they were obviously unable to do it and so the spatial position of the reference flash influenced its timing and *vice versa* (**Study IV**, Fig. 2). Despite a possible interpretation of the data in light of the existence of the "perceptual space-time" (cf., De Long, 1981 or Walsh, 2003 for the suggestion of united processing of space, time, number and any other quantity), the incongruency between the temporal and spatial adjustments (**Study IV**, Fig. 3), again, indicates that different tasks rely on the different aspects of internal representation of the moving stimulus.

Are moving objects processed faster than stationary?

There is a speculation that *moving stimuli are processed faster than stationary stimuli* (e.g., Baldo & Klein, 1995; Nijhawan, 1994; Whitney & Murakami, 1998). Sometimes (e.g., Whitney & Murakami, 1998; Whitney, Cavanagh & Murakami, 2000) **Study II** is referred to, erroneously, as a proof of the advantage of the moving stimulus. However, some physiological (Berry et al., 1999, Fig. 2; Schmolesky et al., 1998) and psychophysical (Gros, Pope & Cohn, 1996; Mashhour, 1964) evidence seems to suggest that motion helps to speed up information processing.

In **Study II** we were interested in the relative, not absolute, RTs and we did not compare times that were necessary to detect moving or stationary stimuli. Having these data we can have a closer look at the absolute RT differences as well. Figure 1 (below) demonstrates the mean RT for short flashes that were presented either (1) in rapid succession (60 ms interval) yielding a good movement impression towards the later presented flash; (2) with a considerable 600 ms delay producing just a succession of the flashes, and (3) only one flash

was presented either in the left or right position from the sharp reference line as a control condition. (See **Study II** Fig. 1, p. 136 for more information). In all cases observers had to make choices either about the direction in which the two flashes were presented (conditions 1 and 2) or about the left-right position of the single flash. It was assured that response was impossible to elicit before the appearance of the test flash the intensity of which varied considerably (8-256 cd/m^2). What we found in **Study II** was that in the good movement condition the intensity of the second flash did not influence the RT as much as it did in two other conditions.
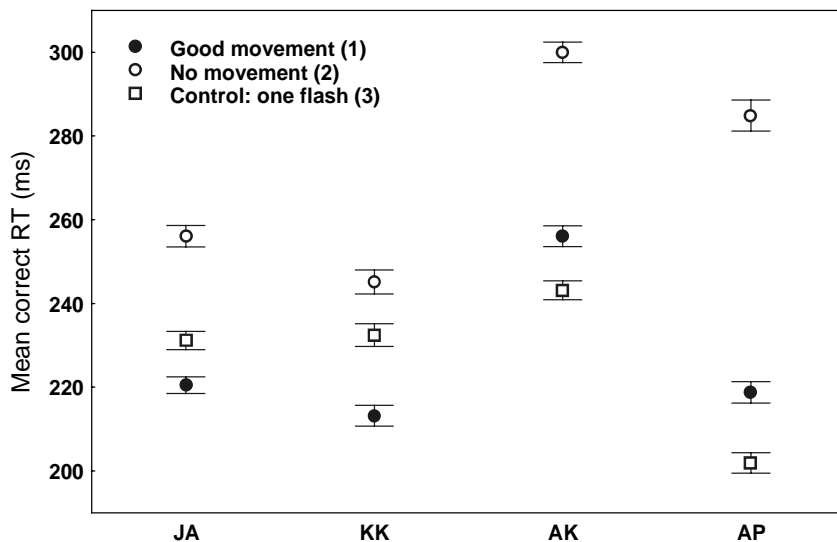
Figure 1. Absolute choice reaction times (RTs) replotted from data in **Study II** (Fig. 1, p. 136). Bars represent ± SEM.

Figure 1 shows that the detection of a no-motion sequence of flashes was the slowest condition for all four subjects. However, there was no systematic pattern for the good motion and single flash conditions: for two observers (JA and KK) RTs were shorter in the good movement conditions and longer in the single flash conditions and for two other observers (AK and AP) vice versa. The lack of systematic pattern (described also by Mashhour in 1964), to say nothing about the relatively small size of differences, do not provide strong evidence for the notion that a moving object is processed faster than a stationary one.

This does not mean that the possible advantage could not be accessible in some other tasks. Only the absolute RT task in the simple form of processing appearing moving objects quicker than stationary objects does not show it. There may still be perceptual tasks where properties of the motion processing

units (as Berry et al., 1999 or Livingstone & Hubel, 1988 have proposed) become advantageous also for phenomenological reality. Actually, several works have even shown that some attributes, for example colour, can be more facilitated than motion of stimuli (Arnold, Clifford & Wenderoth, 2001; Bedell, Chung, Ogmen & Patel, 2003; Moutoussis & Zeki, 1997). The facilitation seems to be relative and to depend on the stimulus conditions and task (Arnold & Clifford, 2002; Bedell et al., 2003; Nishida & Johnston, 2002). These studies made it evident that the motion advantage or disadvantage is nothing absolute and pervasive or even unavoidable. Thus, there is no reason to "mystify" the speed of motion processing. These studies just uncover the properties of different visual processing systems that can have different access to the aspects of the inner representation of stimuli.

Detection of motion onset and offset

It seems that the amount of the perceived motion is determined by the variance of all spatial positions that were passed by a moving object during a certain time interval (Dzhafarov & Allik, 1984). Because the variance of the passed positions is equivalent to the kinematic energy the proposed theory was called the Model of Kinematic Power (Dzhafarov et al., 1993). Applied to the motion detection task it is easy predict when the kinematic energy reaches a fixed threshold value, provided that the movement is noticed as soon the total kinematic energy exceeds this critical level (Allik & Dzhafarov, 1984). In particular, the model predicts that the mean RT to movement onset is a negative exponent power function with exponent close to -2/3 (Allik & Dzhafarov, 1984; Ball & Sekuler, 1980; Dzhafarov et al., 1993; Hohnsbein & Mateeff, 1992; Mashhour, 1964; Tynan & Sekuler, 1982; van den Berg & van de Grind, 1989). The largest challenge to any explanation of motion detection is the fact that the detection of motion onset is virtually equivalent to the detection motion offset (Dzhafarov et al., 1993; Hohnsbein & Mateeff, 1992, 1998). Even more, the detection of the change in velocity appears to be treated as the detection of motion onset due to the mechanism of subtractive normalization which reduces the initial velocity effectively close to zero (Dzhafarov et al., 1993). Thus, only the absolute difference in pre- and post-change speeds has importance in the velocity detection.

As motion-sensitive units (e.g., McKee, Silverman & Nakayama, 1986 or Thompson, 1984) are located in the visual cortex, rather in the retina or LGN, (e.g., Perrone & Thiele, 2001; Priebe, Cassanello & Lisberger, 2003; Simoncelli & Heeger, 2001; Wang, Kaneoke & Kakigi, 2003) it would be logical to look for the relations between the motion-related brain activity and traditional psychophysical responses. In **Study V** visual event-related brain potentials (VEP) to the motion onset or offset and corresponding manual RTs were measured. The participants were asked to press a mouse-button as quickly as they could detect either the onset or the offset of the motion of the field of rectan-

gular elements on the computer screen. Simultaneously the evoked brain potentials (VEP) were recorded. All measures (manual RTs, amplitude and latency of the motion onset VEP peak) were related to stimulus velocity. The comparison of VEP to the motion onset with (the motion onset condition) and without (the motion offset condition) the intention to react manually reveals the salient difference between the two conditions. The peak, most probably the motion onset-related N200 (e.g., Kuba & Kubova, 1992; Markwardt, Göpfert & Müller, 1988) was masked when the task was to react to the motion onset (see Fig. 4 in **Study V**). One possibility is to attribute it to the conscious need to give the manual response (that seems to be confirmed by the simultaneous similarity between the motion onset RT and offset RT VEP curves). Another intriguing possibility of the influence of action intentions has recently been suggested by Bekkering and Neggers (2002). They found in the visual search task that intention to grasp (but not to point to) an object resulted in fewer saccade errors to the objects with action relevant properties (like orientation). It means that in case of the principle of action-relevant processing, the two motion onsets (one to-be-ignored and another to-be-reacted), were not treated equally by perception. The motion onset-related negative peak in the motion offset condition may represent the pure motion encoding (Dzhafarov et al., 1993) that usually remains unaccessible in behavioural tasks. Manual reaction (that requires certainly some decision according to Dzhafarov et al., 1993) changes the pattern of encoding dramatically reversing even its polarity. The reason for that is most likely some form of the "higher-order" influence (cognitive effort, attention, perceptual set or preparation and execution of motor act) that remains unspecified here.

Altogether, data show that motion-related information is differently available for the perception-related systems (i.e., perception, phenomenological "labelling" and the brain).

CONCLUSIONS

Psychology has, at least implicitly, assumed that perception is invariant to the way the question is posed and the answer is given. All studies reported here demonstrate that, although the internal representation of stimulus is exactly or almost the same, the outcome depends on the mode how the information is retrieved from the internal representation. Perhaps the most interesting feature of this study is a striking similarity between memory and perceptual processes that is, despite their often declared similarity, only rarely compared or contrasted. Many results of this study can be interpreted as a demonstration of the fundamental distinction between available and accessible information. Like in case of memory, what is available for the perception, is not necessarily accessible for a particular mode of response. Or, in other words, what is encoded is not necessarily retrieved on this particular occasion at least. At the same time, the conclusion, obtained mostly in the standard psychophysical conditions, demonstrates the considerable flexibility of human motion processing. Visual perception seems to work in the ecologically effective way even in the restricted non-natural environments, thus it is even smarter than we have suspected.

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SUMMARY IN ESTONIAN

INFORMATSIOONI OLEMASOLU JA
KÄTTESAADAVUS LIIKUVATE STIIMULITE TAJUMISEL

Väitekiri lähtub arusaamast, et kuna mälu ja taju on oma olemuselt lahutamatult seotud ning sagedasti ka teadvuse paralleelsete külgedena käsitletud, peaks mõlema toimimine loogiliselt tuginema sarnastele põhimõtetele. Üheks selliseks ideeks, mille kehtivust käesolev väitekiri vaatleb, on olemasoleva ja kättesaadava informatsiooni erinevus. Identsest (või peaaegu identsest) füüsikalisest stimulatsioonist suudavad erinevad tajusüsteemid ligi pääseda just sellise informatsiooni representatsioonile, mis on oluline hetkel lahendatava tajulise ülesande kontekstis. Seega kogu kodeeritud liikumisinformatsioon pole ilmtingimata kättesaadav, vaid selle ammutamine sõltub informatsiooni kasutavast süsteemist. Informatsiooni olemasolu ja kättesaadavuse erinevust liikumistajus illustreerivad viis eksperimentaalset uurimust:

I artiklis ilmneb, et inimese nägemissüsteem pole mitte ainult võimeline liikumismustri alusel hindama kokku põrkavate kehade suhtelist massi, vaid selle teadmise omandamise viisile on olemas ka suhteliselt usaldusväärne introspektiivne ligipääs.

II töö näitab, kuidas erineva heledusega stiimuleid tajutakse suhteliselt suurte ajaliste erinevustega juhul, kui ülesannet lahendab ajastamise või asukoha hindamise süsteem, liikumissüsteemi jaoks muutub heleduserinevus aga tühiseks.

III uurimus käsitleb liikuva objekti ilmumise aja ja asukoha hindamist. Kuigi vaikimisi on neid hinnanguid peetud kongruentseteks, ilmneb, et tegelikult taju jaoks konstantse kiiruse valem *(v=s/t)* ei kehti. Ühe ja sama liikuva stiimuli (ilmuv kriips) asukohta tajuti oluliselt täpsemalt kui ilmumisaega.

IV katsete seeria rakendab liikuvate objektide ajastamise ja lokaliseerimise hindamiseks uudset meetodit — värvimuutusega markeerimist koos ajaliste ja ruumiliste parameetrite lahutatusega. Selgub, et taju jaoks pole aeg ja ruum rangelt eristatavad, vaid eksisteerib, (vähemalt kasutatud ülesandes), ühtne aegruum: sündmuse ajastamine sõltus tugevasti sellest, kus sündmus toimus ja vastupidi (asukohahinnangud olid mõjutatud sellest, millal sündmus toimus). See tähendab, et kui liikuv objekt muutis värvi enne, kui ta mingist märgitud asukohast möödus, hinnati värvimuutuse aeg ka tegelikust hoopis varasemaks ja vastupidi.

V artikkel võrdleb liikumise alguse ja lõpuga seotud aju tingitud potentsiaale (VEP) ja käelisi reaktsiooniaegu (RT) erinevate liikumiskiiruste korral. Ilmnes, et VEP muster sõltub sellest, missuguse instruktsiooniga vaatleja ülesannet täidab.

Seega näitavad väitekirja osaks olevad uurimused, et liikumisstimulatsioonis sisalduv informatsioon on erinevalt kättesaadav mitmetele tajuga seotud süsteemidele (taju ise, aju, fenomenoloogiline "sildistamise" süsteem) ehk et on olemas erinevaid liikumise tajumise viise.

PUBLICATIONS

CURRICULUM VITAE

Kairi Kreegipuu

Citizenship: Estonian
Date of birth: November 05, 1973
Marital status: Married, two children
Address: Department of Psychology, University of Tartu, Tiigi 78,
                 Tartu 50410, Estonia
Telephone: +372 737 5902
Fax: +372 737 5900
E-post: kairi@psych.ut.ee

Education

1992–1996   Undegraduate study (BSc, *cum laude*), Department of Psychology, University of Tartu
1996–1997   Master's study, MSc (psychology), Department of Psychology, University of Tartu
1997–2004   Doctoral study, Department of Psychology, University of Tartu

Professional employment and experience

1995–2003   Research Assistant, Department of Psychology, University of Tartu
1998–2001   Visiting Research Fellow, Department of Psychology, Uppsala University, Sweden
Since 2003 Research Fellow (experimental psychology), Department of Psychology, University of Tartu

Scientific Activity

Main Research Areas:
– Motion perception
– Ecological perception
– Perception and personality and mental abilities, biological correlates
– Introspective ratings
Membership in Professional Organizations:
– Union of Estonian Psychologists

CURRICULUM VITAE

Kairi Kreegipuu

Kodakondsus: Eesti
Sünniaeg: 05. november 1973
Perekonnaseis: abielus, poeg ja tütar
Aadress: Psühholoogia osakond, Tartu Ülikool, Tiigi 78, Tartu 50410
Telefon: 737 5902
Fax: 737 5900
E-post: kairi@psych.ut.ee

Haridus

1992–1996   bakalauseuseõpe psühholoogias (BSc, *cum laude*),
             Tartu Ülikool
1996–1997   magistriõpe, MSc (psühholoogia), Tartu Ülikool
1997–2004   doktoriõpe, psühholoogia osakond, Tartu Ülikool

Erialane teenistuskäik ja kogemus

1995–2003   laborant, psühholoogia osakond, Tartu Ülikool
1998–2001   külalisteadur, psühhologia osakond, Uppsala Ülikool, Rootsi
Alates 2003 eksperimentaalpsühholoogia teadur, psühholoogia osakond,
             Tartu Ülikool

Teadustegevus

Teadustöö põhisuunad:
–   liikumistaju
–   ökoloogiline taju
–   tajumise bioloogilised, isiksuslikud ja võimekusega seotud korrelaadid
–   introspektiivsed hinnangud
Kuulumine erialastesse organisatsioonidesse:
–   Eesti Psühholoogide Liit