The Birth Defect of the Information Processing Approach

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Abstract. Academic psychology is dominated by the information processing approach (IPA) since about six decades. According to the IPA mental activities, i.e. cognition, serve the processing of stimuli in order to reconstruct a representation of the environment. It is argued that this notion is misleading: Mental activities primarily serve the control of voluntary behaviour. In this function, they are striving for anticipations of achievable states. Accordingly, cognition does not refer to the processing but to the anticipation of achievable desired stimuli or states. Two 'ancient' conceptions in psychology already emphasized the crucial role of behaviourally guided anticipations: the reafference - and the ideomotor principle, the former dealing with the basics of perception and the latter dealing with the basics of behavioural control. Speculations are discussed, about how both principles might work together for the control of voluntary behaviour creating by this the mental structure of the perceived world. *(146 words)*

Keywords: Anticipation. Behavioural control. Reafference. Ideomotor. Action-Effect Learning.

1. Introduction

In the first half of the last century academic psychology was dominated by behaviourism. John B. Watson, one of the most prominent maintainer of behaviourism, proclaimed psychology as being *"… a purely objective experimental branch of natural science. Its theoretical goal is the prediction and control of behavior..."* [1, p.158]. At this time only stimuli and responses could be objectively measured. Consequently, behaviourism exclusively explored the formation and structure of stimulus-response relations. The mediating mental processes were excluded from analyses, so that behaviourism often has been ironically named 'black-box psychology'.

However, beginning with the forties of the last century developments in different disciplines heralded a new look: In 1949, Claude Elwood Shannon and Warren Weaver published a thin book entitled 'The mathematical theory of communication’ which provided the mathematics for a measurement of information. One year before Norbert Wiener argued that control and communication can be likewise studied in the animal and the machine. Allan M. Turing discussed in 1950 ‘intelligence’ as being a feature of computing machines and John von Neumann delivered the architecture of such intelligent machines [2,3,4,5].

All these developments strongly influenced academic psychology and when William Edmund Hick from Cambridge reported that the reaction time RT linear increased with the information (the entropy) of the presented stimuli [6], the strong belief emerged that the processes which mediate between stimuli and responses can be explored as information processing. The arising hope, that human information processing can finally be understood by its simulation in computers was confirmed, only nine years later, by Alan Newell and Herb Simon from Carnegie Mellon University [7]. They implemented a computer program, the so called ‘General Problem Solver’, which was able to solve simple problems like the tower of Hanoi. The information processing approach was born and Ulric Neisser gave the new movement its name by his seminal book “Cognitive Psychology” [8]. Neisser defined ‘cognition’ as referring *“…to all the processes by which sensory input is transformed, reduced, elaborated, stored, recovered, and used.”* [8, p.4]. Accordingly, from this time on up to today academic psychology analyses all these processes, i.e. perception, attention, memory, language, thinking, learning etc.

I experienced these new developments as a student and I shared of course the enthusiasm for the information processing view at this time. It was a good feeling, to be part of a breakup, by which light was shed into the black box of the behaviourist and it was probably due to this enthusiasm that it took me a long time until I started to suspect that the information processing approach might be basically wrong. I have in particular two reasons for my scepticism.

2. The Fault of the Information Processing Approach

First, the information processing approach suggests that there is one and only world which delivers the information for its mental representation via stimulation. However there is no one and only world. I will take a very simple example for demonstration. Figure 1 presents an elementary sensory input which we typically perceive or represent as being two squares. However there are likewise eight triangles or the shape of a house with some extra brackets, or an octagon with extra brackets etc. As it is in this simple example, it is always the case that there are many alternative interpretations of the environment around us from which we realize only a tiny part in every moment. Accordingly, the critical question is not how we process the “given” information but rather what determines the selection of the particular information, we are processing, what is a complete different affair.

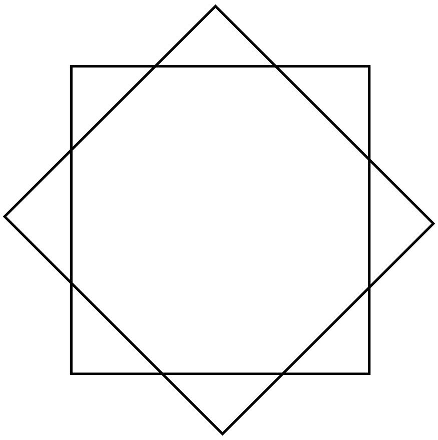

Fig. 1. Two squares, but also eight triangles, the shape of house or an octagon with some extra brackets.

Second and even more important: Any action, as simple as it may be, produces changes of the sensory input. Whether we move our finger, our eyes and even if we just talk, in any case we produce some new sensory input for ourselves. Thus, our mind continuously has to distinguish what of the sensory input has been induced by ourselves, and what has been caused otherwise. Without distinguishing self-induced sensory effects from other sensory input, no valid perception would be possible. Accordingly, organisms have to learn what the sensory effects of their actions are, i.e. not stimulus-response relations but action-effect relations are crucial for behavioural control.

To sum up: The information processing approach fortunately overcame the black box of the behaviourism but unfortunately it inherited the disastrous fixation on stimulus-response relations: All cognition, so again the assumption, starts with the impact of stimuli. However organisms and above all human beings typically do not respond on stimuli but they almost always act in order to create stimulations or situations they are striving for. To have overlooked this goal-oriented character of almost all behaviour, I call the ‘birth defect’ of the information processing approach**.** The information processing approach would have been better focused not on the processing of incoming stimulation but on the generation of desired stimulations – especially as the importance of behaviourally guided anticipations of action-effects has been emphasized already in several conceptions before. The most prominent are the Reafference Principle and the Ideomotor Principle.

3. The Reafference Principle: Control of Perception by Anticipation

The Reafference Principle (henceforth RP) has been first discussed by Erich von Holst and Horst Mittelstaedt in a paper published 1950. In the introduction the authors explain their concern as follows [9, p.464]:

“We do not ask for the relation between an afference and the resulting efference i.e. the reflex but rather depart with the efference and ask what happens in the CNS with the afference which has been caused by it, which we call the reafference” (translated by the author).

Figure 2 presents a schematic illustration of what von Holst and Mittelstaedt assumed to happen with the ‘reafference’. According to the RP any efferent motor command causes via corresponding neuronal networks some action in an effector (e.g. an eye movement). Additionally changes in the environment may happen. The immediate sensory consequences of the action are called reafferences and the sensory input from other sources are called exafferences. Both are fed back via corresponding neuronal networks for perception. So far it is a matter of course. The critical assumptions of the RP concern two points: 1) Any efferent motor command goes along with a corollary discharge – the so called efference copy and 2) The efference copy and the reafference cancel each other out. As a result, only the ex-afferences are transmitted for perception

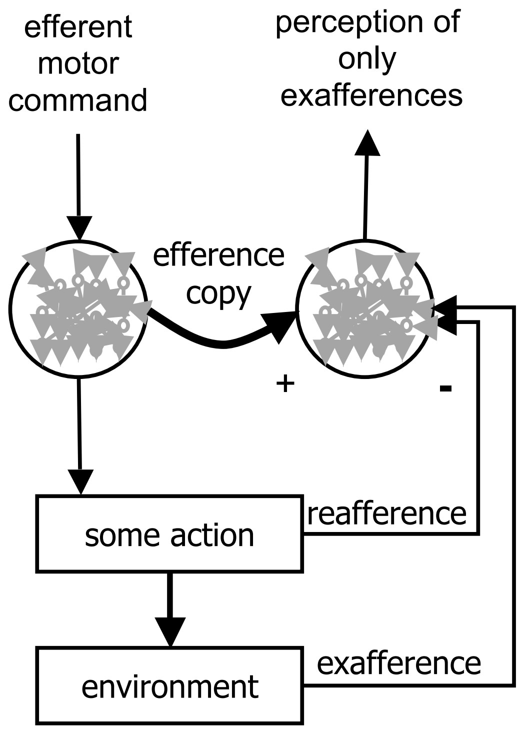

Fig.2. A simplified schematic outline of the reafference principle

The RP provides an elegant solution to the issue of how organisms separate sensory input induced by themselves from input induced by environmental sources. There are many observations which confirm the validity of the RP [cf. 9]: For example, in patients suffering from Polyneuritis the kinaesthetic feedback from the muscles is generally reduced. If these patients are pressing a hand against a wall they report a feeling as if the wall would be flexible like rubber. According to the RP the phenomenon appears because the kinaesthetic reafference is less strong than expected by the efference copy so that the difference between the copy and the reafference becomes positive what corresponds to a situation in which the wall would move a little bit away, exactly what is perceived.

Or imagine an experiment conducted by the physician Kornmüller. Kornmüller paralysed eye muscles by an injection of curare but gave nevertheless the order to move the gaze to the right. Trying to look to the right, participants reported to see a short flip of the whole environment to the right. Again, the reason is that the copy of the eye movement command anticipates a shift of the retinal image which fails to appear what corresponds to a situation in which the environment would move with the gaze shift, exactly what the participants in these experiments have seen.

The RP is also responsible for that it is difficult to tickle oneself, what has been very nicely experimentally demonstrated [10]. The reason is that if we tickle ourselves the efference copies of our movement commands cancel the resulting sensations out so that their tickling effect vanishes or is at least reduced.

Despite all this convincing evidence, there remains a problem: Motor commands and sensations are incommensurable to each other. Consider for example an eye movement. The motor command for an eye movement refers to the contraction of at least three pairs of muscles whereas the resulting shift of the retinal image refers to spatially distributed signals from the retina. That is, the efference copy cannot be a pure copy of a motor command but must contain information about the expected reafference – otherwise it's impossible to see how the copy might cancel out the arriving reafference. Thus, the question arises how motor commands are translated into anticipations of to be expected sensory consequences. We will come back to this issue.

4. The Ideomotor Principle: Control of Behaviour by Anticipation

The other theoretical conception which already emphasized the central role of action-effect relations is the ideo-motor principle (henceforth IMP). The IMP has British and German roots. In Britain Thomas Laycock and William Carpenter and in Germany Johan Friedrich Herbart, Hermann Lotze and Emil Harless already propagated the idea that the motor outcome influences retroactively the motor control [cf. 11]. William James finally tied together the ideas of all these scholars to the Ideo-Motor Principle in his seminal Book "Principles of Psychology" published more than 120 years ago [12]. Figure 3 presents a schematic illustration of the basic ideas, reduced to the fewest possible terms.

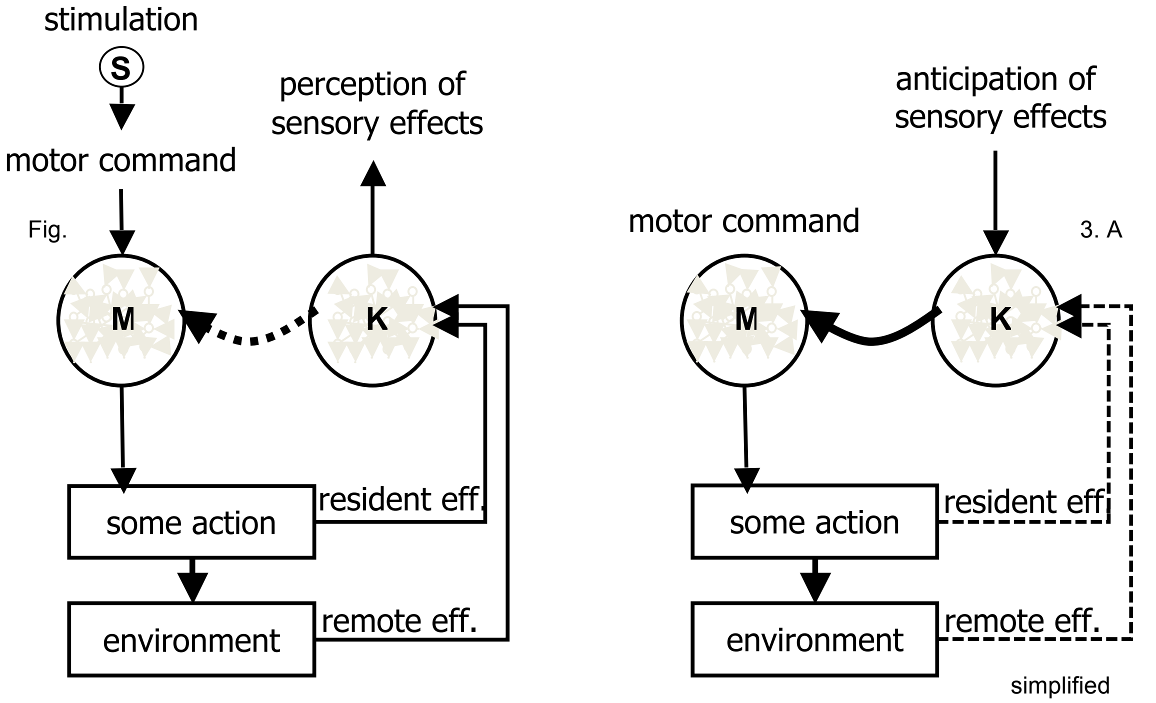

Fig. 3. A simplified schematic outline of the Ideomotor Principle,

In the beginning we have some external stimulation ‘S’ which triggers a motor command ‘M’ causing via corresponding neuronal networks some action and changes in the environment, which are fed back by what have been called by James resident and remote effects ‘K’. Furthermore, James assumed that by repetition new connections are formed between neuronal representations of ‘K’ and ‘M’ (Fig.3, left side). These new connections, he assumed, change the flow of activation in the following way [12, p. 586]:

“*K may be aroused in any way whatsoever (not as before from S or from without) and still it will tend to discharge into M; or, to express it in psychic terms, the idea of the movement M's sensory effects will have become an immediately antecedent condition to the production of the movement itself. …Here, then, we have the answer to our original question of how a sensory process which, the first time it occurred, was the effect of a movement, can later figure as the movement's cause.*“

The gist of the IMP is that actions become connected to their sensory consequences so that anticipations (the idea) of such consequences gain the power to trigger the movements that formerly brought them about. In other words: voluntary movements or actions become determined by anticipations of their own sensory consequences (cf. Fig. 3, right side).

The IMP was widely acknowledged in the beginning of the last century. However, for the upcoming behaviourism the assumption that behaviour is determined by something unobservable like an idea was a sacrilege so that behaviourists rejected the IMP in total. For example: Edward Thorndike mocked the IMP in his presidential lecture at the APA Congress in 1913, by saying [13, p.101]:

„Shocking as it may seem, it can be shown that the orthodox belief of modern psychologists, that an idea of a movement tend to produce the movement which is like it, is a true child of primitive man´s belief that if you sprinkle water in a proper way your mimicry tends to produce rain“

Thus it happened that the IMP remained almost without any significant influence on academic psychology for decades. However in the last years the IMP experienced a renaissance especially in experimental psychology. For example, Shin, Proctor, and Capaldi noticed in a recent comprehensive review that*: „As of week 1 of February 2010, PsycINFO listed 134 entries with ‚ideomotor/ideo-motor‘ in the titles and 517 results with it as a keyword.“* [14, p.943].

5. An experimental demonstration of the IMP

Many of the experimental demonstrations of the IMP follow a methodological proposal made by Anthony Greenwald more than 40 years ago [15]: In a typical choice reaction time experiment the response alternatives are to be connected with different but distinctive sensory consequences so that a possible impact of the sensory consequences on the responses, they are the result of, can be examined. The following example is taken from a paper published by Kunde, Koch, and Hoffmann [16].

The authors came from the stimulus-response-compatibility phenomenon: If there is a dimensional overlap between stimuli and responses in terms of space, time or intensity, compatible stimulus-response assignments are accomplished faster than incompatible assignments. [cf. 17]. For example, if participants have to respond to quiet or loud tones with a strong or a soft keystroke, they respond faster if the strong keystroke is assigned to the loud tones and the soft keystroke is assigned to the quiet tones than if the assignment is reversed. Furthermore, the authors argued, if sensory response effects are really necessary antecedents of voluntary responses, as claimed by the IMP, the same compatibility phenomena as between stimuli and responses should appear between responses and effects. Thus, to demonstrate the IMP, response-effect compatibilities are to be shown.

In the experiment participants were requested to press a key either softly or strongly in response to imperative colour stimuli. Doing so, they produced either a quiet or a loud effect tone. The critical variation concerns the assignment of the effect tones to the keystrokes. Strong keystrokes either produced loud and soft keystrokes produced quiet tones (compatible mapping), or vice versa strong keystrokes produced quiet and soft keystrokes produced loud tones (incompatible mapping).

The results show that participants responded significantly faster if their responses triggered tones of compatible intensity than if they triggered incompatible tones. This response-effect compatibility phenomenon has been proven to be a very robust one. The phenomenon occurs in the dimension of space, time, and intensity [18,19,20,21]. In all these experiments, the effects were not intended but appeared incidentally after the execution of the response. Their impact on response latencies proves that representations of these non-intended effects were activated before the responses were selected and initiated.

The use of response alternatives that differ in intensity additionally allowed a qualification of response execution. For example, if participants are required to complete a soft or a strong keystroke the peak force that is reached provides an appropriate measure of response execution, allowing to explore whether response-effect compatibility would affect not only response latencies but also response execution. This was indeed the case. The intensity of the effect-tones uniquely affected the peak forces of soft as well as of strong keystrokes in a contrast like fashion. As Figure 4 illustrates, loud effect-tones reduced and quiet effect-tones intensified the peak forces of intended soft keystrokes as well as of intended strong keystrokes.

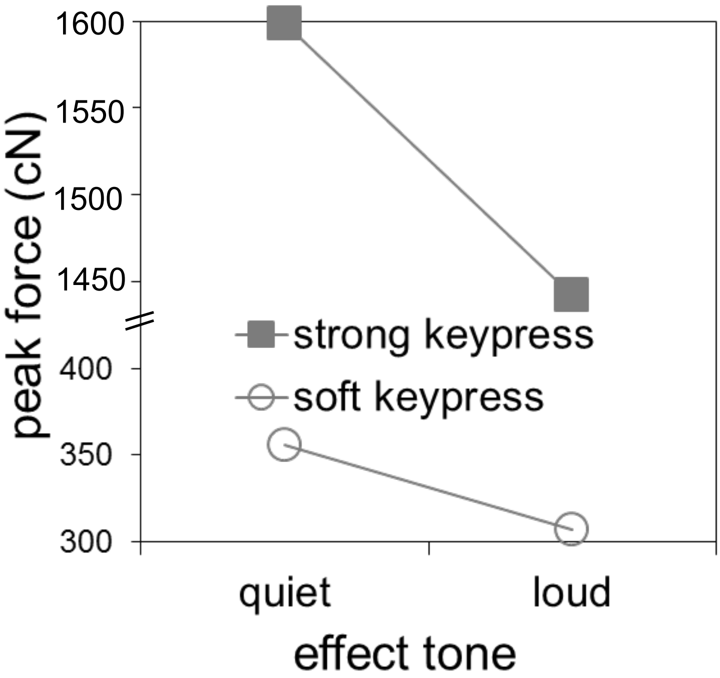

Fig. 4. The peak force for intended strong and soft keystrokes in dependence on the intensity of the effect-tones the keystrokes produced (after Kunde, Koch, Hoffmann, 2004).

For an appropriate account of the found contrast, it is to notice that peak forces indicate the intensity of the tactile feedback by which participants start to reduce the force of their hand because they feel the intended force (strong or soft) to be reached. In this view, the data show that less strong tactile feedback is required to feel the intended force completed if a loud effect-tone follows and stronger tactile feedback is needed if a quiet effect-tone follows. Figure 5 illustrates two possible accounts for this contrast. A simple feedback loop for the execution of a prescribed pressure force is depicted: The imperative stimulus determines the set point (the proximal reference), i.e. the proprioceptive feeling is anticipated which has to be reached in order to realize either a strong or a soft keystroke. The difference between the set point and the current feeling (the current proximal feedback) determines the appropriate motor commands which are activated until the proprioceptive feedback from the fingertip and from the muscles signal that the set point is reached.

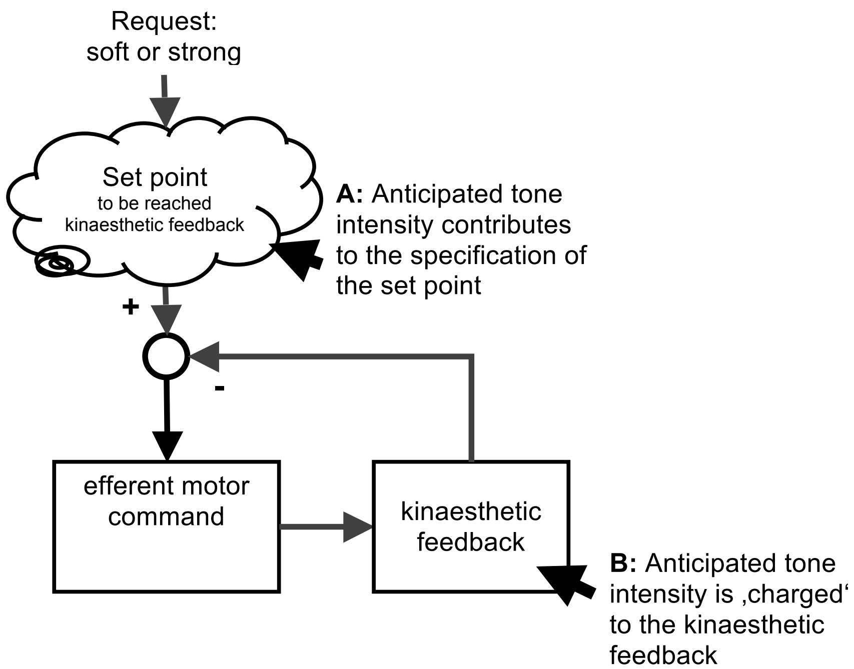

Fig. 5. Illustration of two possible points of action at which anticipated effects might affect behavioural control.

Within this loop the additionally anticipated intensity of the distal effect-tone might on the one hand (A) influence the set point so that the set point is somewhat enhanced if a quiet tone is anticipated, and the set point is somewhat reduced if a loud tone is anticipated. In this way the intended force of the keystroke would be adjusted in order to compensate for the anticipated force of the effect tones. On the other hand (B) it might be that the anticipated intensity of the distal effect-tone is charged to the proximal feedback so that an anticipated loud tone earlier evokes the feeling that the set point is reached and an anticipated quiet tone delays somewhat the appearance of this feeling. Both mechanisms provide an account for the contrast effect and they both may conjointly contribute to it. In any case, the present data provides profound evidence that anticipations even of unintended response effects are not only involved in the selection and initiation of voluntary actions but also take part in the control of their execution.

6. The Interplay of the Reafference and the Ideomotor Principle: Structuring the 'Mental World' by Anticipation

The central matter of psychology are experience and behaviour of humans. The RP deals with a basic part of experience – perception, and the IMP deals with a basic part of behaviour – the control of voluntary behaviour. Both principles rely on coincidences between motor and sensory activations and this certainly is not an accident. On the contrary: I believe that such sensomotor coincidences finally structure perception as well as behaviour.

Coincidences between motor and sensory activation already play an important role in the control of the most elementary motor unit – the muscle. Figure 6 (left side) illustrates the basic elements of the so called gamma spindle loop: A skeletal muscle with enclosed spindles is depicted. The spindles serve as sensors for the current length of the muscle. They start to fire if the muscle is stretched or if the spindle itself is contracted by Gamma activation. Additionally there is Alpha activation by which the skeletal muscle can be contracted. The critical point is that the spindles have an excitatory connection to the alpha neurons so that a loop control of muscle length is created. Accordingly, there are two principle routes by which a muscle can be and is typically contracted, by direct commands via Alpha neurons and by a control loop in which Gamma activation delivers a set point and the spindles work as controller.

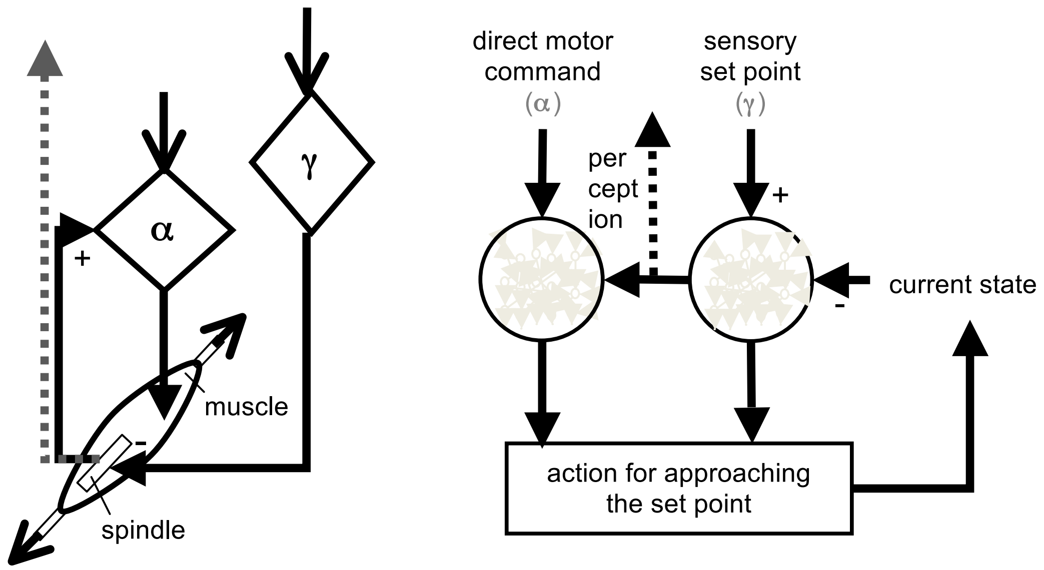

Fig. 6. A simplified illustration of the basic elements of the Gamma-spindle-loop (left side) and its principle structure (right side).

On the right side of Figure 6 the principle structure of the gamma-spindle loop is depicted in general terms: A set point is generated which can be understood as the anticipation of a desired state or a goal (e.g. the desired length of the muscle). A comparison of the desired to the current state (e.g. accomplished by spindles) delivers the impulse for some action by which the difference between the current and the desired state is reduced (e.g. alpha activation). Simultaneously, the differences are forwarded for perception and they are used in order to tune the activations of an additional direct motor pathway for triggering actions to achieve the set goal.

The point of the matter is the redundant control via two paths: a direct motor pathway and a sensory feedback loop. My basic assumption is that this principle might be realized not only for the control of muscles but on all levels of behavioural control.

Figure 7 illustrates a tentative structure: For the sake of simplicity only four levels are distinguished. On the highest level desired effects (goals) in the environment are specified (e.g. to grasp a cup of coffee). On the next level corresponding effector unspecific set points are generated (e.g. the egocentric location of the cup is fixed to which all limbs have equal access). At this point it is not yet decided e.g. whether to grasp the cup with the right or the left hand. Next, corresponding set points for a certain limb are specified (e.g. the posture of the right arm that brings the right hand to the cup). Finally, the set points for the corresponding muscles are generated (in our example the Gamma activations for the muscles of the right arm and hand might be fixed in order to execute a corresponding grasping act). Concurrently, direct motor activations are tuned step for step and level for level in dependence on the continuously reported differences between the forwarded set points and the confirmed current states. These differences simultaneously provide the data for perception.

If we focus on one of these levels you certainly recognize the general architecture of the gamma spindle loop with the two paths: a sensory control loop and a direct motor path. And if we look on the whole architecture we find the reafference principle, i.e. the anticipation of to be expected reafferences (the set points or desired states) as well as the ideomotor principle, i.e. the determination of motor commands by anticipated sensory input, distributed over different levels.

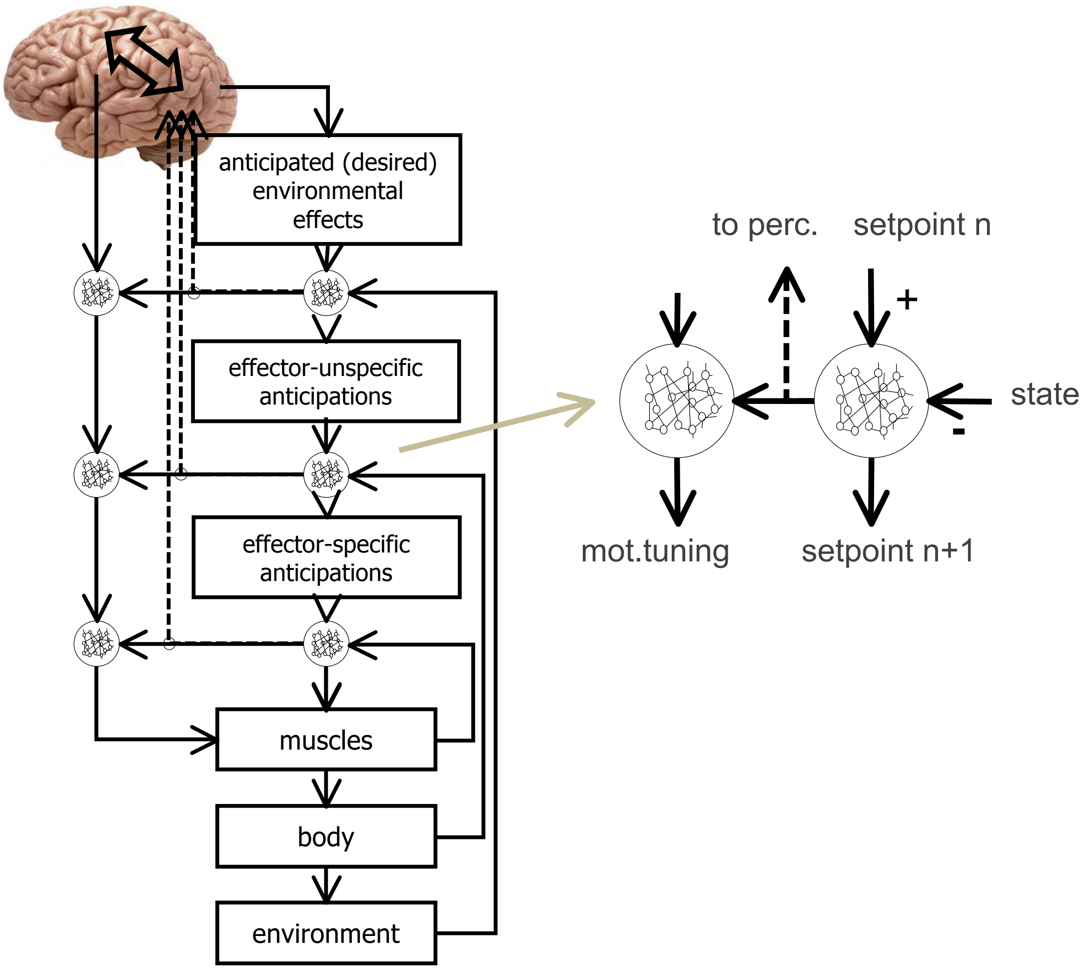

Fig.7. A tentative cascade of anticipative sensory loops and direct motor commands for the control of voluntary behaviour (left side) with an enlarged illustration of one level (right side)

A concrete act will be finally realized by a continuous cascade of sensory control loops running down from top to bottom und back from bottom to top as well as by consecutively tuned direct motor activations.

The learning dependent formation of such structures refer to several relations at each of the different levels [22,23]: First, representations of states which are worth to aim at (set points or goals) are to be distinguished and represented. Second, attention (perception) has to be tuned to behaviourally relevant differences between desired goals and current states. Third, it has to be learned how such differences are to be translated into desired states (set points or goals) on the respective next subordinated level, for example it has to be learned which postures are to take in order to reach a certain point in space. Finally, it has to be learned how to tune the accompanying direct motor commands to current differences between goals and states. As a result of such continuous distributed learning on different levels of abstraction perception and behaviour might be adopted to each other so that what is anticipated really happens as a result of behaviour.

These, of course, are far-reaching speculations which I think however are worth to become elaborated and examined in order to see how far they reach.

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