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An integrative dual-route model of rhythm perception and production

Introduction

sensorimotor synchronization is considered as one of the most important experimental paradigms in the field of psychomotricity in order to illuminate the underlying processes of action control in view of the coupling of both, perception and action (Vorberg, 1996). This kind of anticipatory behaviour (Butz, 2003) is a crucial ability in everyday life and an elementary skill for playing a musical instrument in particular.

In contrast to musical novices, expert drummers are able to synchronize their taps without, or at least with a very low, negative asynchrony. Although there have been several attempts to find an explanation for the negative synchronization error, the causes for this phenomenon still remain unclear (Repp, 2005).

However, two essential processes responsible for synchronization have recently been identified, and can be characterized separately: One is the implicit automatic anticipation and the other the explicit processing of temporal information (Miyake, 2004; Repp, 2005).

Studies from neuroimaging have also clarified two distinct systems for automatic and cognitively controlled time measurement which seem to work in both a partly parallel and partly concurrent manner (Lewis & Miall, 2003).

Thaut (2005) argues that strong connections between stages of the auditory pathway and the cerebellum are responsible for a mostly subconscious processing of sensorimotor information. At this subcortical level, the colliculus inferior and the nucleus cochlearis (dorsal) project to the cerebellum while they also receive signals from the cerebellum (Casseday, 1995).

Integrative approach

Taking into account that there seem to be different cognitive pathways, an integrative dual-route model of rhythm perception and production is proposed here (Fig. 1). The model is based on fundamental psychological principles of perception, action control and relevant neurobiological findings regarding rhythm processing and sensorimotor synchronization mentioned above.

According to the „expanded closed-loop model for movement control“ by Schmidt & Lee (1999), it includes different modules on different cognitive levels like "Stimulus" (Input), "Movement" (Output), "Stimulus identification", "Response selection" and "Response programming" (see Schmidt & Lee, 1999, p. 43). Here, the stimulus identification and response selection is illustrated by three different modules (evaluation, comprehension and relevance), which work partly parallel as well as sequential. Response programming is administrated by a central executive (see Kluwe, 2006). The model also integrates open-loop processing as well as closed-loop circuits, including different feedback components (proprioceptive and exteroceptive feedback loops) and a „reference of correctness" (Schmidt & Lee, 1999) as important prerequisites for a tight coupling of perception and action. The main assumption of the model is the differentiation between the "cognitively controlled" and "automatic" pathway (direct and preattentive trigger).

Dual-Route Model

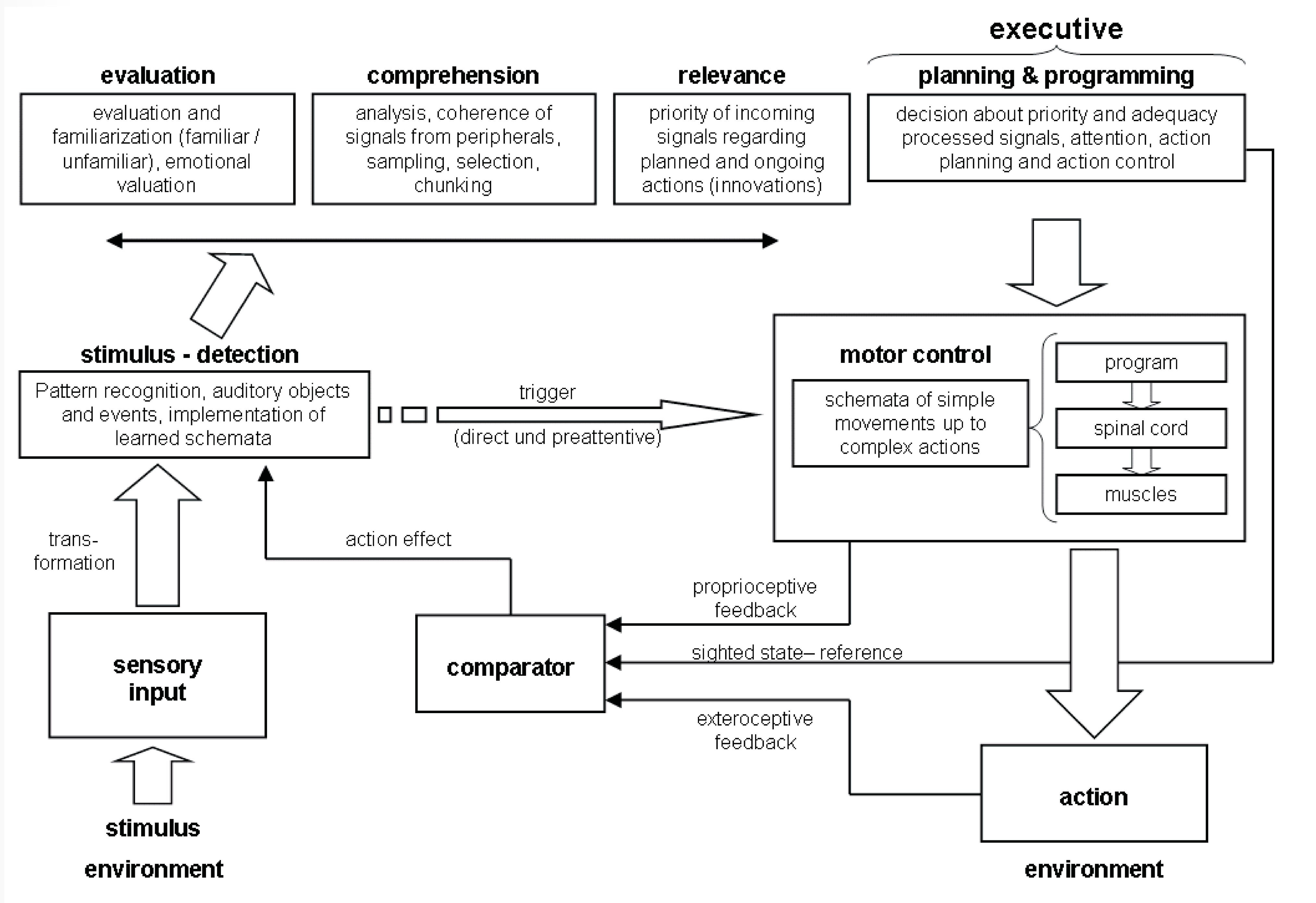

Figure 1. Integrative dual-route model of rhythm perception and production.

Experiment

In the following study on synchronization behaviour of professional drummers, a dual-task paradigm (Baddeley, 1986) was used during synchronization tapping similar to the experiments of (Miyake, 2004) in order to elucidate the effects of higher brain functions such as attention. The aim was to examine whether expert drummers show a change in tapping performance when they have to draw their attention to another task. Unlike in the study of (Miyake, 2004) it was assumed that timing accuracy of very precise rhythmic action at interstimulus-onset interval (IOI) 600 ms depends on attentional resources of higher brain functions. If these monitoring processes (timing control and correction) are disturbed by an additional task that minimizes the capacity of working memory (e.g., phonological loop), this should result in an increased negative mean asynchrony (NMA), because timing control falls back on the "automatic" pathway.

Method

Participants:

Ten professional drummers volunteered in the experiment (two women; ages 20-44). All participants were right-handed and had extensive drum training, with a minimum 10 years of instruction.

Materials & Equipment:

The basic stimulus material for the pacing signal (log drum sound, low pitch) consisted of three metronome sequences with different tempi: IOI = 400, 500 and 600 ms. Another log drum sound (high pitch) was used as a feedback sound for the taps.

Procedure:

Participants were required to synchronize their finger taps as precise as possible to a given metronome sequence in blocks of separate trials under different conditions (Baseline & Concurrent).

Analysis:

Asynchronies were extracted from the MIDI output files into a spreadsheet program using another custom made program written in C, and sorted according to the conditions Baseline and Concurrent. The data analysis for the Baseline condition started with the first 30 taps in each of the trials which had no concurrent task. This was also done for the Concurrent condition, in which the word lists were displayed at the beginning of a trial. total number of 480 datasets (consisting of 30 taps x 24 conditions x 2 sessions x 10 participants = 14.400 taps) were generated for the two conditions. Means and standard deviations of asynchronies were calculated per trial and condition.

Results

In contrast to other experiments on SMS with nonmusicians (see Miyake et al., 2004), it was shown that participants were able to synchronize their taps with a very low NMA under normal conditions (Baseline) at all three tapping tempi, while they performed with increased variability and a significantly increased NMA at IOIs = 500 and 600 ms when they had to concentrate on a secondary word memory task while synchronizing (Concurrent).

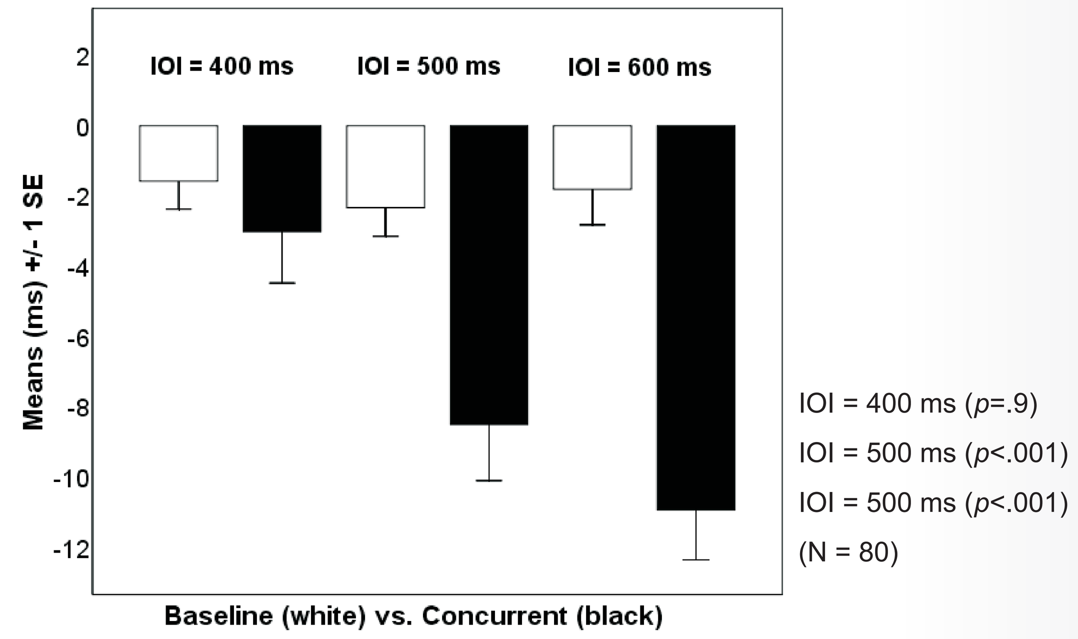

Figure 2. Means and between-trials standard errors of the mean asynchronies in the tapping task at three different IOIs (400, 500 and 600 ms) under the two tested conditions Baseline and Concurrent.

	Tempo		
	IOI = 400ms	IOI = 500ms	IOI = 600ms
Baseline	-1.77 (5.94)	-2.07 (4.37)	-2.45 (5.06)
Concurrent	-1.88 (7.03)	-5.2 (7.1)	-7.59 (6.93)
BC-Diff	-0.11	-3.13	-5.14
t-test	p = 0.90	$p < 0.001$	$p = < 0.001$
Effect size	0.01	0.48	0.75

Table 1. Means of the asynchronies in ms (with standard deviations), BC-Diffs (difference between Baseline and Concurrent conditions), t-tests for paired samples on the mean values of the asynchrony among trials and effect sizes for the

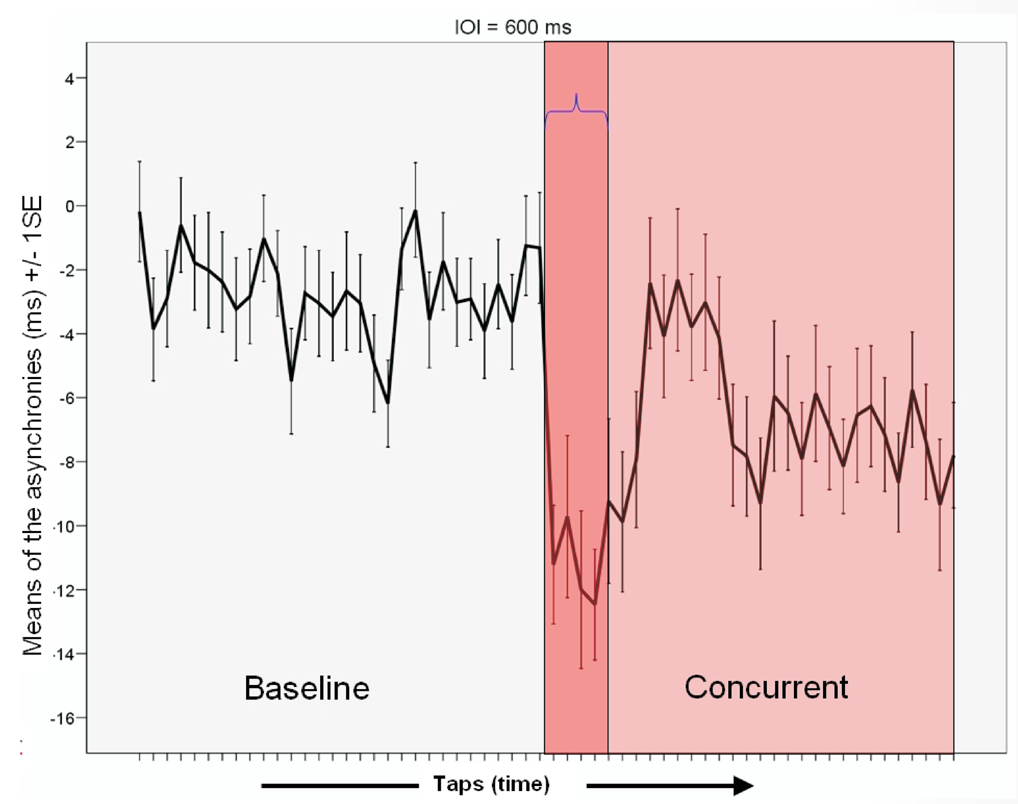

Figure 3. Means and between-trials standard errors of the mean asynchronies in the tapping task at IOI = 600 ms under the two tested conditions Baseline and Concurrent.

Discussion

The proposed dual-route model integrates significant mechanisms of sensorimotor synchronization, which are based on a tight coupling of perception and action as an essential requirement for timing control. In particular, two distinct systems for automatic and cognitively-controlled mechanisms are illustrated here. They seem to work in both a partly parallel and partly concurrent manner at different distributed stages, guaranteeing a robust but flexible and adaptive motion control which is crucial when playing a musical instrument.

The results of the experiment provide further evidence of the existence of two different cognitive pathways mentioned above. It can be concluded that timing accuracy of very precise rhythmic action depends on both expertise and attentional resources of higher brain functions. If these monitoring processes (timing control and correction) are disturbed by an additional task that minimizes working memory capacity, timing control falls back on a secondary processing pathway that is driven by an "automatic" system.

Furthermore, the NMA could be the result of different delay times of two distinct, but simultaneously acting, cognitive pathways. That is, fast information processing at low (subcortical) levels provides close links between sensory peripherals and motor centers, while sensorimotor information processing at higher levels requires attention and working memory resources.

According to this, the tendency to tap ahead of the pacing signal (the NMA) seems to be a kind of preattentive automatic timing behaviour, which is typically true for the tapping performance of untrained participants. In contrast, trained experts like professional drummers make use of cognitively controlled monitoring processes that depend on attentional resources.

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