Sound and Movement

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Summary

In this thesis, I investigated how we detect and select sounds, distill information, and use them to perform appropriate actions in the environment. I put particular focus on the interaction between sound perception and motor behavior, put that into context of embodied cognition, and sought to unravel its neural underpinnings. I either modified the cognitive context and tested to what extend this modification altered the motor system, or – in the final study of the thesis – I modified the motor system and tested how this altered cognitive capacities.

After a general, yet brief overview of the challenges in the fields of sound perception and motor control in the introductory *Chapter 1,* I circled around the following questions in the subsequently summarized studies:

i. Does valence of sound affect the excitability of the corticospinal motor tract?
ii. Does speech perception through the observation of gestures alter M1 excitability?
iii. What strategies can be used to intercept moving sounds?
iv. Do non-temporal aspects of musical sound affect movement timing?
v. What are the cortical correlates of audiomotor and audiovisual integration?

In *Chapter 2,* I investigated how emotional processing of non-verbal auditory stimuli leads to increased corticospinal tract excitability, to what degree this modulation is lateralized in response to the valence of the stimuli, and whether delivering sounds to the left ear, right ear, or both ears may yield lateralization in motor facilitation. During the experiment, subjects listened to sounds (monaurally and binaurally), and single-pulse TMS was delivered to either left or right primary motor cortex. The EMG activities recorded from the contralateral abductor pollicis brevis muscle revealed significant changes in motor-evoked potentials, which is interpreted as an increase in corticospinal tract (CST) excitability in response to unpleasant as compared to neutral sounds. That increase was lateralized as a function of stimulus valence: Unpleasant stimuli resulted in a significantly larger CST excitability in the left hemisphere, while pleasant stimuli yielded a greater CST excitability in the right one. Furthermore, the motor evoked potentials were larger when listening to unpleasant sounds with the left than with the right ear. In the chapter, I argued in

detail that the facilitation of CST excitability in the left primary motor cortex in response to unpleasant sounds suggests a general preference for a direct motor-auditory projection for processing threatening auditory stimuli. This system may have been developed to allow for rapid fight-or-flight responses to potential dangerous stimuli.

In *Chapter 3,* I continued with altering the cognitive context to test for corresponding effects in the motor system. I addressed the question whether or not observation of newly learned hand gestures paired and not paired with words may result in changes in the excitability of the hand and tongue areas of motor cortex. Once again, I used single-pulse TMS and measured motor excitability, this time in tongue and hand areas of left primary motor cortex. Subjects viewed video sequences of bimanual hand movements associated or not associated with nouns. I found higher motor excitability in the tongue area during the presentation of meaningful gestures (noun-associated) as opposed to meaningless ones, while CST excitability of hand motor area was not differentially affected by gesture observation. These results let me conclude that the observation of gestures associated with a word results in activation of articulatory motor network accompanying speech production.

In contrast to the previous two, in the experiment outlined in *Chapter 4,* subjects had to move themselves, which offered the possibility to investigate more dynamical issue rather than the analysis of static percepts. I examined the ability to intercept a laterally moving virtual sound object by controlling the displacement of a sliding handle. I tested whether the interaural time difference (ITD) of an arriving sound might be the main source of perceptual information for successfully intercepting the object. The experimental findings revealed that in order to accomplish the task, one might need to vary the duration of the movement, control the hand velocity and time to reach the peak velocity (speed coupling), while the adjustment of movement initiation does not facilitate performance. The overall performance was more successful when the subjects employed a time-to-contact (tau) coupling strategy. Sound seems to contain prospective information to guide goal-directed actions.

Coming back to the topic of the valence of sound, in *Chapter 5*, I sought to tackle the influence of its 'color'. The origins of consonance and dissonance in terms of acoustics, psychoacoustics and physiology have been debated for centuries, indeed, but their plausible effects on movement synchronization had largely been ignored. I asked whether timing, as in the previous chapter, plays a role in processing consonant versus dissonant sounds. In this chapter, I summarized the effects of musical consonance/dissonance on sensorimotor timing in a synchronization-continuation paradigm during which participants performed reciprocal aiming movements. I compared movements synchronized to either consonant or to dissonant sounds and showed that they were differentially influenced by the degree of consonance of the sound presented. The difference was present after the sound stimulus had been removed. The performance measured after consonant sound exposure was more stable and accurate, with a strong information/movement coupling (tau-coupling) and pronounced movement circularity. It appears that the neural resonance representing consonant tones yields finer perception/action coupling, which, in turn, may explain the prevailing preference for these types of tones.

From the first chapters it should be clear the perception of sound is affected by various factors. In the particular case of speech sound, just looking at facial motions can have a major influence. Incongruity between sounds and watching somebody articulating them may cause a bias toward the visual percept. This phenomenon is referred to as the McGurk effect. In *Chapter 6,* I addressed brain mechanisms underlying (the failure of) audiovisual as well as audiomotor multisensory integration in the McGurk effect. In the experiment, listeners had to recognize auditory syllables while silently articulating congruent/incongruent syllables (motor condition) or observing videos of a speaker's face articulating the syllables (visual condition), and EEG responses were recorded during all the conditions. When incongruent syllables were observed and when silently articulated, perception of sound was diminished. This was accompanied by significant amplitude modulations in the beta frequency band in right superior temporal areas. There, the event-related beta activities during congruent conditions were phase locked to responses evoked during the auditory only condition. This implies that proper temporal alignment of different input streams in right superior temporal areas is mandatory for both audiovisual and audiomotor speech integration.

In the finalizing epilogue, *Chapter 7*, I recalled the aforementioned research questions point by point:

i. Valence of sound does affect the excitability of the corticospinal motor tract: Unpleasant stimuli increase the CST excitability in left M1 and pleasant ones in right M1.
ii. Speech perception through observation of gestures alters M1 excitability in the tongue area if gestures are associated with words.
iii. To intercept moving virtual sounds, individuals employed a time-to-contact (tau) coupling strategy and adjusted kinematic parameters such as movement duration, peak velocity and time to reach the peak velocity.
iv. Movement timing measured after exposure to a consonant metronome is more precise and less variable than the timing following a dissonant metronome.
v. Differences of proper versus improper audiomotor or audiovisual integration are primarily visible in the superior temporal area where it correlates with the degree of beta-frequency phase synchronization.

Despite all efforts summarized in the thesis, the interaction between sound perceptions and motor actions at behavioral and neural levels is still not fully understood. Future research is required especially to comprehend more complex, audiomotor skills such as those found among musicians and visually impaired people.