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How does sound influence visuo-motorics in professional pianists

Does the congruency effect exists in music?

An EEG-study

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Abstract: The congruency effect has mainly been studied in linguistics, but the existence in music has never been investigated. By the use of electroencephalography (EEG) this exploratory study aims at studying the influence of sound on visuo-motor integration in professional pianists, while focussing on the congruency effect. Auditory and visual stimulus pairs of single music notes were presented with different stimulus onset asynchronies (SOA) of 100ms and 300ms. Trials were presented in two different block, in which one required a motor response (active) and the other did not require a motor response (passive). The congruency effect has been investigated by focussing on two EEG-components: the N400 and Gamma Band Activity (GBA). In the shortest SOA condition (-100ms), incongruent stimulus pairs evoked a higher peak of the N400 compared to congruent stimulus pairs. Focussing on GBA, in the passive block a higher level of activity was found in frontal regions compared to parietal regions. Conceivably, our results indicate a possible presence of the congruency effect in music and a difference in level of GBA between frontal and parietal regions while presenting (in)congruent stimulus pairs of single music notes.

Introduction

Playing a music score by sight is a complex action which requires a lot of practice. In this multidimensional cognitive activity perception and action are intimately intertwined. By transforming perception to action a motor plan is generated from where patterns of finger movements within a precise time frame are formed. This transformation consists of patterns, timing and the positioning of finger movements within the visuo-spatial domain (Sergent, 1993). The repetition of movements in association with specific stimuli leads to an automatic association between stimuli, a motor plan and execution. A proof of a progressive automation is given by the evidence that after practice motoric representation activates smaller areas (Jäncke, Shah & Peters, 2000). The automated process of creating a motor plan while reading scores happens mostly in supplementary motoric area's (SMA) and pre-motoric area's (Gerloff, Corwell, Chen, Hallett & Cohen, 1997). These brain structures are not only activated during music playing, but also when musicians listen to music (Lahav, Saltzman & Schlaud, 2007). Activation has been found in fronto-parietal areas when musicians listen to music and these areas, associated with movement, are even active during listening to music unconsciously (Haueisen & Knüsche, 2001). Components as pitch, melody and rhythm processed by different brain structures have to be considered constructing these movements (Bengtsson & Ullén, 2006).

An interesting sample of subjects, who are professionals in sensorimotor interaction, can be found in pianists. After years of training, involving the relationship between visual perception, action and auditory feedback, pianists are able to generate automatic responses to the visual presentation of a musical score (Drost, Rieger, Brass, Gunter & Prinz, 2005a). Moreover, also auditory presented music stimuli generate motor activity in pianists (Haueisen et al., 2001).

As both music listening and music reading are able to elicit motor activity in music experts, it is interesting to study if there is a crossmodal interaction between reading a score and listening to musical notes. Drost, Rieger, Brass Gunter & Prinz (2005b) investigated the influence of a simultaneously presented auditory note on the execution of a visually presented musical note with pianists. They found pianists to be faster when the auditory and visual notes were congruent (same note) and slower when they were incongruent. D'ausilio and colleagues, with a similar paradigm, varied the stimulus onset asynchrony (SOA) in order to see when in time the sounds caused more facilitation and inhibition on score execution on the keyboard (D'ausilio, Brunetti, Delogu, Santonico and Olivettie & Belardinelli, 2009). The authors found facilitation when the auditory cue was congruent to the imperative stimulus and presented with a SOA of -300ms. At the same latency, the incongruent condition reaction time didn't significantly differ from a no-sound baseline. By contrast, interference was found when the auditory cue was incongruent to the imperative stimulus with a SOA of -100ms. At this SOA, no significant influence of cue was found in the congruent condition.

D'ausilio proposes an explanation of this dissociation by combining two findings from other studies. On one hand, the time necessary to terminate an audio-motor transformation and preactivate a full motor representation is 300ms (Pizzamiglio, Aprile, Spitoni, Pitzalis, Bates, D'Amico & Di Russo, 2005). On the other hand, a 300ms time interval is found to be associated with top-down processes in music behaviour (Shahin, Roberts, Chau, Trainor & Miller, 2008). So, 300ms after stimulus presentation top-down processes can take advantage of the audio-motor transformation (facilitation in congruent condition) or inhibit it (no interference in the incongruent condition). In case of the -100ms SOA, probably other processes are involved. Since no facilitation is found, it is likely that motor translation evoked by the auditory cue has not been finished yet. The presentation of the stimuli evoke a cross-modal interaction between the analyses of these stimuli. Interference could be the result of an incongruency when both auditory and visual stimuli are converted into motor plans.

The results of D'ausilio et al. (2009) are a first evidence of dissociation between the process of auditory inhibition and facilitation of motor planning in music performance. However, by means of only behavioural information, (accuracy and reaction times) it is difficult to understand what processes are causing such dissociation. An excellent method for further investigation on sensorimotor integration in music is electroencephalography (EEG). With this method the time course of cognitive processes can be investigated in a very precise way because of its precise temporal measurements.

In this EEG-study we aimed at studying the influence of sound on visuo-motor integration in professional pianists. This study will mainly focus on the presence of the congruency effect in visuo-motorics and furthermore has an exploratory goal; by testing a small group of pianists we want to investigate if our design is capable of demonstrating the presence of interesting trends of results that makes it worth to proceed into a more extensive investigation.

We will test the influence of congruent and incongruent auditory stimuli on the execution of a visual music-score (imperative stimulus). We will vary the SOA between the auditory cue and the visual imperative stimulus. In order to obtain information on the time course of the sensorimotor interaction we will record EEG traces.

N400

An interesting component of EEG can be found in the N400, which is a negative going peak in a time window of 250-500ms post stimulus onset. The N400 reflects cognitive processes which are often analysed in priming paradigms where prime and target words are semantically related/unrelated (Kutas & Hillyard, 1980; Brown & Hagoort, 1999).

A sufficient amount of linguistic studies the N400 has been related to the enhancement of processing words (Forster, 1999), or semantically incongruent sentences (Kutas et al, 1980). Not many studies have been focussing on the N400 with the implementation of music. In a study of Koelsch, Kasper, Sammler, Schulze, Gunter and Friederici (2008), the idea has been claimed that music is able to prime a word as well as a sentence can. In this study the N400 component was used to verify the idea of shared brain mechanisms related to the processing of semantic meaning. Participants were presented a visual target word, preceded by either an auditory sentence or a music excerpt that was semantically related or unrelated to the target word. After presentation of both stimuli participants were asked to indicate whether the prime and target were semantically related or unrelated to eachother. From EEG-recordings no differences in the N400 between the two conditions were found, indicating that music contains semantic information. A comparable study (Daltrazzo & Schön, 2009) used music-related stimuli in which music excerpts had a duration of 1sec. On one hand, they focused on single words primed by music excerpts. On the other hand the reversed was investigated, in which music excerpts were primed by single words. Their results showed a priming effect in both directions and a higher N400 related to incongruent stimulus pairs.

In our experiment, instead of using music excerpts and words, we will use sounds and visual stimuli (music scores), both related to a single music note. In this way we focus on multi-modal processing of music related stimuli only, with the exclusion of language related stimuli.

GBA

Another electrophysiological indicator which can be useful for our theoretical purposes is gamma band activity (GBA). GBA reflects electrophysiological activity from ~30Hz an above. It has been found that this activity reflects synchronized oscillating networks formed by disparate neuronal networks (Başar-Eroglu, Strüber, Schrürmann, Stadler & Başar, 1996). GBA has also been related to multi-sensory object processing (Yuval-Greenberg & Deouell, 2007). In the Yuval-Greenberg study, participants were presented with congruent and incongruent stimulus pairs consisting of pictures (visual stimulus) and vocalisations (auditory stimulus) of animals. An enhancement of GBA was found when stimulus pairs were congruent compared to incongruent stimulus pairs. A comparable study of Schneider, Engel & Debener (2008) found similar results with asynchronously presented auditory-visual stimulus pairs. These consisted of photographs of natural objects, rated in a norming study (Schneider, Engel & Debener, 2008) and environmental sounds of natural objects from the same norming study. They found congruent stimulus pairs to elicit a stronger GBA compared to incongruent pairs.

The last two cited experiments about GBA used pictures, objects and semantically related/unrelated auditory stimuli. In our experiment we'll be using visual and auditory stimuli of single music notes which already proved to evoke specific priming effects (D'ausilio et al., 2009).

Mu-rhythm

A third interesting EEG-component is the rolandic mu rhythm including two frequencies (10Hz and 20Hz), which co-vary but not in a harmonic way. Namely, before the execution of a movement the 10Hz activity starts to suppress earlier than the 20Hz, while the 20Hz activity shows a more clear and earlier rebound after the movement. Studies have shown that this rebound of the peak at 20Hz is related to resetting of the control system involving the motor cortex after movements (Kilner, Baker, Salenius, Hari, & Lemon, 2000). Interestingly, mu rhythms are not only present when motoric movements are executed, but also while exclusively observing movements of others (Hari, Forss, Avikainen, Kirveskari, Salenius, Rizzolatti, 1998). Furthermore, Jeannerod (2001) explains an important finding of the development of simulated behaviour, after the repetition of cycles of action and perception, which are reflected in the modulation of the mu rhythm. In our study we will not be analysing mμ-rhythms. But, because of the highly association between mμ-rhythms and voluntary and involuntary execution of movement, this EEG-component could be interesting for further research.

Previous studies showed an association between the presentation of incongruent stimulus pairs and a higher peak of the N400. Coherent with these studies we expect higher amplitudes of the N400 in the incongruent condition, compared to the baseline condition. Moreover, we expect to find lower amplitudes of the N400 in the congruent condition, compared to the baseline condition.
Since GBA activity is found to be greater during the presentation of congruent multisensory pairs, we also expect to find an enhancement of GBA in the congruent condition compared with the incongruent condition.

METHOD

Participants

4 professional pianists (3 male, mean age 39.3, range 32-59) with four different nationalities (Dutch, Spanish, Italian, German) with at least 5 years (mean = 10.3 years) of formal training at the conservatorium were selected for participating in the study. All participants received monetary compensation for participation. Informed consent was obtained from all participants.

Material and apparatus

We used visual and auditory stimuli. Our visual stimuli were three images representing the notes G, A and B in G-clef (see fig. 1 for an example). The auditory stimuli included a burst of white noise and the digitalized piano sounds G4, A4 and B4. All of the auditory stimuli were presented for 400ms with the same loudness.

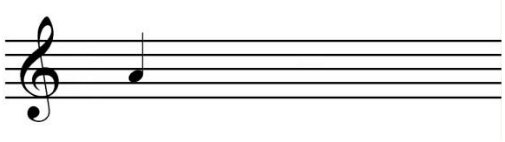


Fig1; Visual stimulus (A-note)

For the registration of motor responses we used a 4-octave piano-keyboard (MIDI-keyboard, Midistart USB). As well for the registration of the behavioural data and the presentation and randomization of the stimuli we used MAX, cycling '74 (version 5.1.8) running on a Mac-pro computer. EEG-data was collected from 64 active electrodes (Biosemi) placed on the participant's head according to the 10-20 system. Two external electrodes were used as reference-mastoids and four external electrodes were used to filter out ocular movements from the EEG-data. For the registration of EEG-waves we used Actiview and for further analyses of the EEG-data BrainVision Analyzer was used. To assure a perfect synchronization of the motor responses and the EEG-data we used a customized response box. Next to receiving and transmitting EEG-data this response box receives a code every time a motor response was performed on the MIDI-keyboard. While EEG-data was being redirected to a laptop running Actiview, this code marks the EEG-data at that very exact moment.

Procedure

Participants were presented with two different blocks of trials: an 'active block' and a 'passive block'. The order in which these blocks were presented was randomized between subjects.

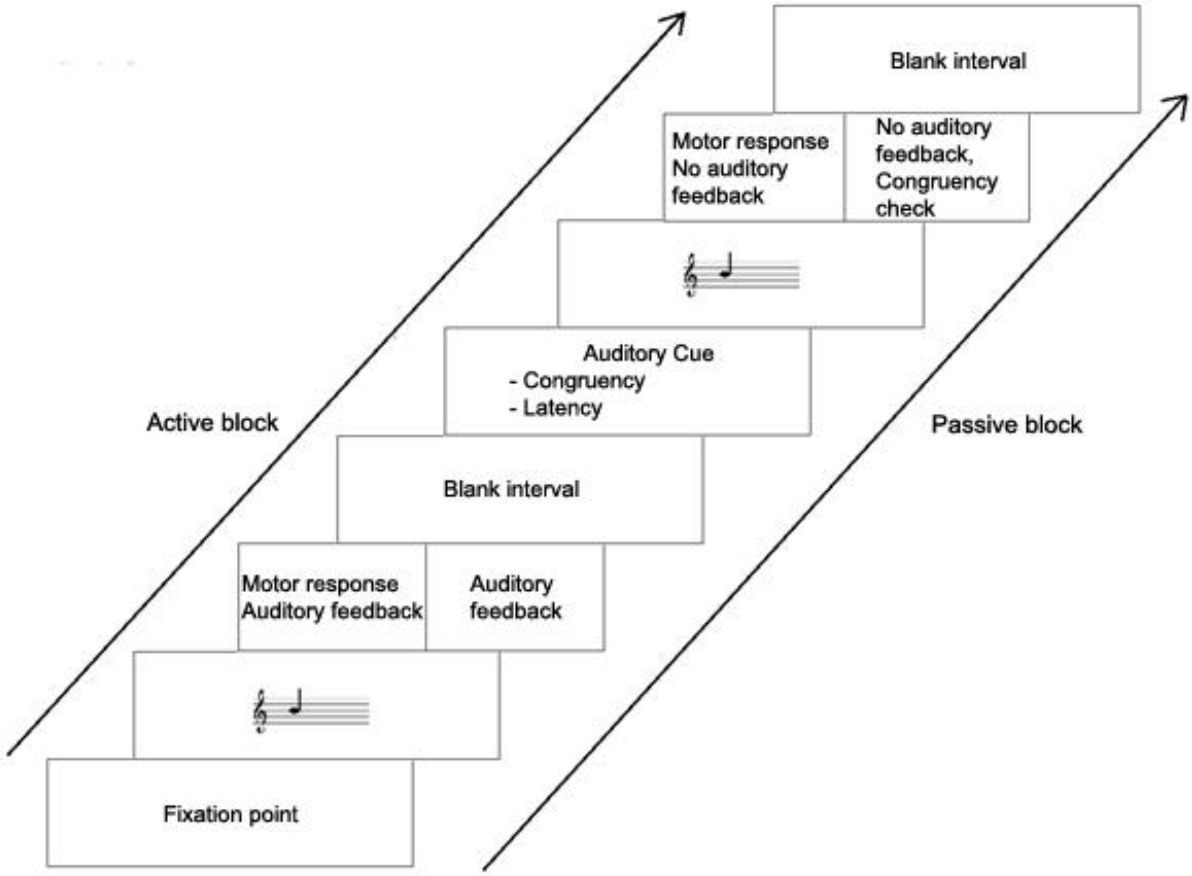
Active block

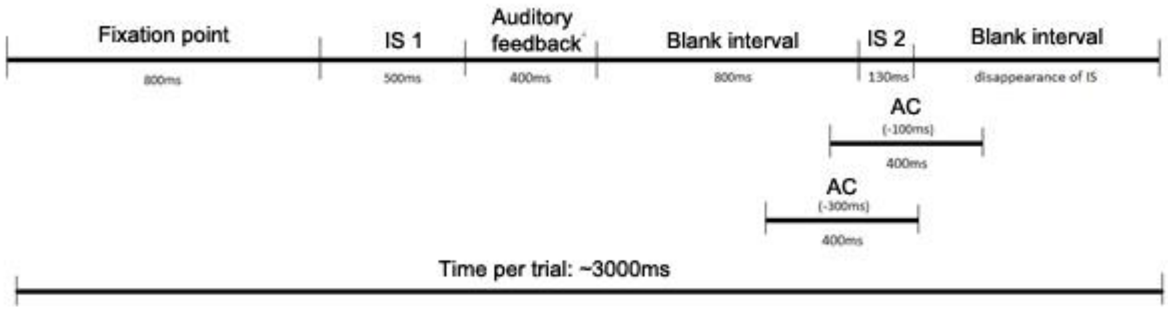
All fingers of the participant's right hand were placed on the keyboard with the thumb placed on the G4, index finger on the A4, middle finger on the G4 etc. In the 'active block' the instruction was to play all the scores appearing on the screen as fast as possible. A trial started with a 800ms fixation point placed in the position in which the note to be played appeared on the screen. Then the first note to be played, which was always a B4 and called the imperative stimulus 1 (IS1), appeared on the screen. At the moment of the motor response (pressing the corresponding key on the keyboard) the IS1 disappeared and the corresponding sounds (the piano sound of B4) is presented. Then, after a new blank interval of 800ms, a second score appeared on the screen (imperative stimulus 2, IS2) which could be either a G4 or an A4. IS2 presentation was preceded by an auditory cue (AC) presented 100ms or 300ms before the presentation of IS2. This AC could be either congruent when it was matching the IS2 or incongruent when it was not matching IS2. In a control condition the AC was a burst of white noise. After the participant's motor response there wasn't any auditory feedback and a blank interval appeared on the screen for 800ms before a new trial started.

Passive block

This block was exactly the same as the 'active block' except that no motor response to the imperative stimuli was asked. Every imperative stimulus was shown for 500ms. While sitting in the same setup as in the 'active block' the participant was presented with the same amount of randomized trials. In order to keep the participant's attention focused on the stimuli, the question if IS2 is congruent or incongruent to the preceding AC was asked (varying after 20-25 trials). When the AC consisted of a burst of white noise it had to be defined as incongruent. In case of a congruent or incongruent sound the subject was asked to resp. press '1' or '0' on a qwerty-keyboard (See fig. 2 for a timeline of both blocks).

The purpose of this listening-block was to compare mechanisms of audio-visual interaction in a solely perceptual way with the ones accuring when an action was produced as a function of score reading. We expect no significant differences in measurements between the two blocks and in this way exclude the probability that the process of facilitation and interference is completely dedicated to a motoric component.


Blank interval
Motor response
No auditory
feedback
No auditory
feedback,
Congruency
check
Auditory Cue
- Congruency
- Latency
Active block
Passive block
Blank interval
Motor response
Auditory feedback
Auditory
feedback
Fixation point


Fixation point
IS 1
Auditory
feedback
Blank interval
IS 2
Blank interval
800ms
500ms
400ms
800ms
130ms
disappearance of IS
AC
(-100ms)
400ms
AC
(-300ms)
400ms
Time per trial: ~3000ms

RESULTS

Behavioural data

In our experiment, the experimental task was to respond as fast as possible to the visual imperative stimulus by pressing the corresponding key on a piano-keyboard. Because in the passive block no motoric response was required only data from the active block was used for behavioural analyses. Trials followed by an incorrect response and trials with a response time more than 1000ms after the presentation of the imperative stimulus, were excluded from analyses.

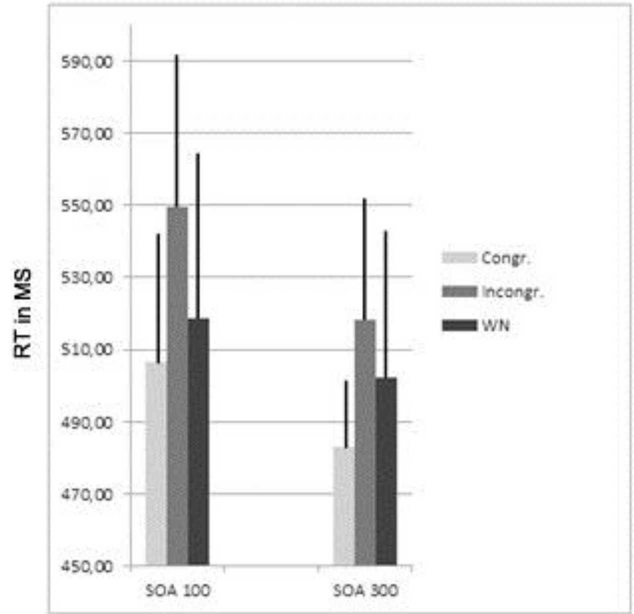


Fig. 3; Mean RT's for both SOA-conditions and all congruencies

A two-way repeated measures ANOVA with the two factors Congruency (congruent, incongruent, baseline) and SOA (-100, -300) was employed to analyse the behavioural data. The Greenhouse-Geisser correction was applied whenever the assumption of sphericity was violated. There has been indicated a significant main effect of SOA ($F(1,3) = 14.50$, $p = .032$) in which the mean RT in the -100ms SOA condition (mean=525,06ms, SD=42,59ms) was longer compared to the -300ms SOA condition (mean=498,62ms, SD=31,30ms). No significant main effect of congruency was found ($F(2,6) = 5.82$, $p = .088$) nor a correlation effect of SOA and congruency ($F(2,6) = .665$, $p = .502$) (See fig. 3 & table 1 for mean RT's and SD).

RT (in ms)	Congruent		Incongruent		Baseline	
	M	**SD**	***M***	**SD**	***M***	**SD**
SOA -100ms	506,65	35,34	549,67	44,46	518,85	47,96
SOA -300ms	475,66	29,49	518,13	33,239	502,08	31,167

Table 1; Mean RT's and SD's for all conditions (active block)

EEG-data

The same trials used for behavioural analyses has been used for analysing the EEG-data. A selection of electrodes has been made to reduce the amount of data. By visual inspection, electrodes which revealed the most relevant differences between the conditions, has been selected for analysing (frontal: F7 & F8; parietal P9 & P10).

N400

The amplitude of the N400-component showed its peak in a 320ms-400ms time window post-stimulus onset of the IS2. The grand averages for all congruencies in both SOA conditions has been compared in this time window for the selected electrodes.

A 5-way (blocks x congruency x SOA x hemispheres x electrodes) repeated measures ANOVA was performed on the EEG-data. While no main effect was found, a significant interaction effect was found for congruency * SOA ($F(2,6) = 5.69$, $p = .041$). Specifically, the N400 in the congruent condition is significantly lower than the N400 in the incongruent condition at a SOA of -100, while they are not different at a SOA of -300. Notably, the N400 showed its lowest peak in the congruent -100 SOA-condition, compared to all the other conditions (See fig. 4).

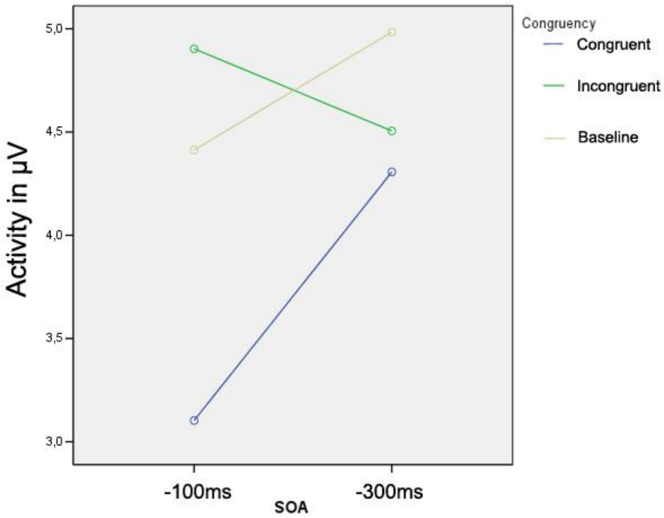


Fig. 4; significant interaction effect for congruency x SOA in both blocks (active and passive block)

We also conducted separate analyses for the two blocks of trials (active and passive blocks). A 4-way (congruency x SOA x hemispheres x location) repeated measures ANOVA in the active block revealed a significant interaction effect (fig. 5) of congruency * electrode ($F(2,6) = 6.336$, $p = .033$). The peak of the N400 showed its highest amplitude in the incongruent condition in the parietal area, while the lowest peak was found in the congruent condition in the parietal area.
No significant main effects or interaction effects were found in the analysis of the passive block.

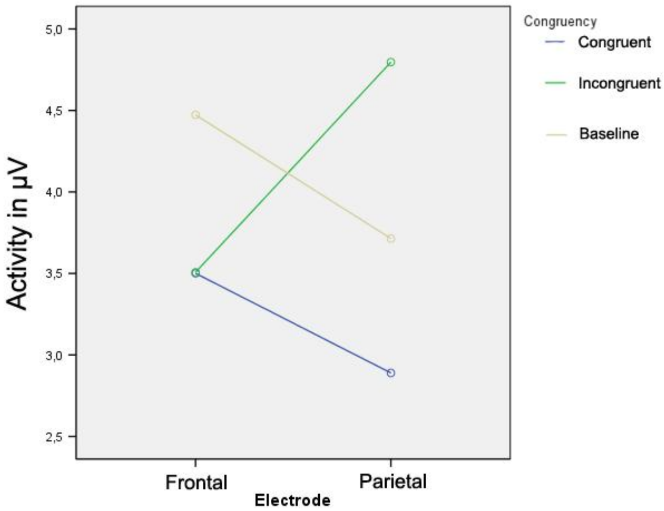


Fig. 5; significant interaction effect congruency * electrode in active block

GBA

The selected electrodes in the ERP-analyses were also used for analysing the GBA (F7, F*, P9 & P10). A Fast Fourier transformation was used to calculate the average gamma activity (30-40Hz) for the selected electrodes in a time window of 0-600ms from stimulus onset of the IS2.

When a 5-way repeated measures ANOVA was employed on both blocks (passive and active), a significant interaction effect of block x electrode (*f*(1,3) = 14.23, *p* = .033) was found. Specifically, frontal activity of GBA is higher in the passive condition compared to parietal activity in this same block. Notably, in the active block grontal and parietal activation of GBA is almost similar (see fig. 6). No main effects were revealed.

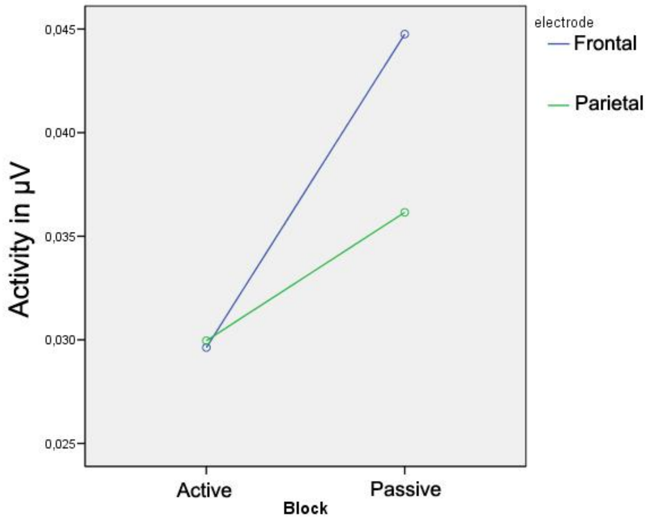


Fig. 6; Significant interaction effect (GBA) of block x electrode

A 4-way repeated measures ANOVA on the active block solely revealed a 3-way interaction between Congruency, SOA and Hemisphere (*F*(2,6) = 25.526, *p* = .002) An enhancement of the GBA activity in the baseline condition was found as a function of SOA in the left hemisphere. In the right hemisphere a more general enhancement of GBA activity is found in the baseline condition. Notably, all three congruency conditions show an enhancement in GBA activity as a function of SOA (fig. 7).

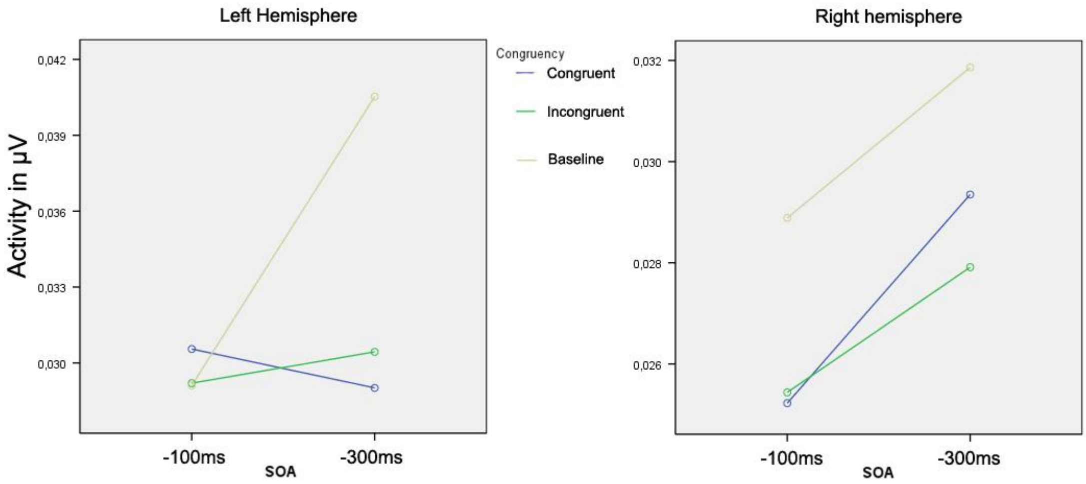


Fig. 7; significant interaction effect in GBA of congruency, SOA and hemisphere

DISCUSSION

The aim of the present study was to investigate the influence of sound on visuo-motor integration in professional pianists. In this exploratory study our main focus lied on the congruency effect in music. The previous experiment of D'ausilio and colleagues (2009) uncovered a dissociation including a process of facilitation and interference. Facilitation occurred when a congruent auditory cue preceded the imperative stimulus at a latency of 300ms, while, at the same latency, the incongruent condition didn't differ significantly from a no-sound baseline. On the other hand, interference was found when the auditory cue was incongruent to the imperative stimulus with a latency of 100ms. At this same latency no significant influence of cue was found in the congruent condition. In our study, to obtain more specific information about the cognitive processes related to this dissociation, EEG traces were recorded.

Behavioural findings

In our study our goal was to reproduce D'ausilio's et al. (2009) findings on a behavioural level and investigate this process in more depth by using EEG-recordings. From behavioural analyses, we found a main effect of SOA, whereas the mean RT in the -300 SOA condition was shorter compared to the mean RT of the -100 SOA condition. We didn't find a correlation effect between type of congruency and SOA. This unfortunately means we couldn't reproduce D'ausilio's et al. (2009) findings. Noteworthy are the trends found in our data, which are comparable to the findings D'ausilio found. In fact, in the -300 SOA condition the RT for the congruent condition is faster compared to both the incongruent and baseline condition (see fig. 3; table 1). Also the -100 SOA condition shows comparable findings with this dissociation. Namely, the RT in the incongruent condition is slower compared to the congruent and baseline condition, while the latter does not differ much compared to the difference in RT between the incongruent and baseline condition.
The inability to reproduce the findings of D'ausilio and colleagues (2009) could be attributed to the small number of participants. Testing a greater number of professional pianists could solve the problem of the great variation found in our study.

EEG findings

The main purpose of this study was to investigate the congruency effect in a sensori-motor interaction by using EEG. Different EEG-components related to the congruency effect (N400 & GBA) were used for analysing which are discussed separately below.

N400

Studies focusing on the N400 concern mainly about linguistic features, where the N400 is related to cognitive processes associated with semantically related/unrelated prime and target words (Kutas and Hillyard, 1980; Forster, 1999; Brown and Hagoort,1999). Enhanced processing of a stimulus is found when it's preceded by a related prime word. Priming studies involving music-related stimuli validated the presence of the priming effect in musicians (Drost et al, 2005a/b;). Even a dissociative process of facilitation and interference in pianists were found when different SOA's were added (D'ausilio et al. 2009).

Few studies have investigated the priming effect in music while focussing on EEG-components. One of those studies (Koelsch, Kasper, Sammler, Schulze, Gunter and Friederici, 2004), claimed the idea that music is able to prime a word as well as a sentence can. In this study the N400 component was used to verify the idea of shared brain mechanisms related to the processing of semantic meaning. While a sentence as well as a music excerpt was used to prime a word, no differences in the N400 was found, indicating that music contains semantic information. A comparable study (Daltrazzo & Schön, 2009) used music-related stimuli in which music excerpts were used with a duration of 1sec. On one hand, they focused on single words primed by music excerpts, and on the other hand the reversed was investigated, in which music excerpts were primed by single words. Their results showed a priming effect in both directions and a higher N400 related to incongruent stimulus pairs.

In contrast with previous studies, we used solely music related stimuli consisting of auditory and visual stimuli from a single music note. In our study we want to demonstrate that with the exclusion of any language related stimuli, the congruency effect exists in music. We used the N400 to prove the presence of this congruency effect.

We expected to find a higher amplitude of the N400 when an incongruent auditory cue preceded a visual stimulus, compared to the incongruent and baseline condition. In our ANOVA analyses, when both blocks were analysed together, we found no main effect of congruency. But we did find an interaction between congruency and SOA. The amplitude of the N400 in general is higher in the incongruent condition compared to the congruent condition. Our findings are in line with the idea the N400 is a marker for mismatch between two presented stimuli. With these findings we could say, with more assurance than with other studies, music solely is able to elicit the congruency effect.

It is more difficult to explain why there is an increase of activity in the congruent condition between -100 and -300 SOA conditions. It is worth to notice that baseline and congruent conditions share the same trend as a function of the SOA.

Third, independently from the SOA we notice that incongruent and baseline conditions are both higher than the congruent one.

The highest peak of the N400 is found in the incongruent condition in the -100 SOA condition, while the lowest peak can be found in the congruent condition in the same condition (Fig. 4).

When the active and passive block are analysed separately, no differences of the N400 between the conditions were found. Despite, the findings of the N400 in the incongruent -100 SOA condition may point out a trend in the amplitude of the N400, and further research with a greater amount of participants could clarify this process.

Further analyses in the active block revealed a significance when frontal and parietal regions were compared (see fig. 5). In the parietal region the N400 showed a higher peak in the incongruent condition compared to the congruent condition. This is in line with findings of centro-parietal areas related with maximal distribution of the N400 (Koelsch et al., 2004). So, in the active block a congruency effect is found in the parietal regions as shown by a higher N400 in the incongruent condition compared to the incongruent condition. Notably, this congruency effect is only found when the two SOA conditions (-100ms and -300ms) are analysed together. When taking a closer look at frontal activation, the N400 in the congruent condition is quiet similar to the incongruent condition. But, both differ from baseline.

Another noteworthy observation form this analyse is the same slope of the congruent condition and the baseline condition between the frontal and the parietal region.

GBA

It has been found that GBA is associated with synchronized oscillating networks formed by disparate neuronal networks (Başar-Eroglu et al., 1996). It has also been found that GBA is related to multi-sensory object processing (Yuval-Greenberg et al., 2007). Both Basar and Yuval studies used pictures and sounds of animals. So far, no GBA studies have used stimuli related to music notes. In our experiment, with the use of auditory and visual stimuli of single music notes, we want to demonstrate that GBA is also related to multi-sensory processing of solely music related stimuli.

Differences in GBA between frontal and parietal regions were found when both blocks (passive and active) were combined in our analyses. Namely, in the passive block GBA was higher in the frontal regions compared to parietal regions. In the active block a same amount of GBA activation was found when frontal and parietal regions where compared.

The difference in GBA between the active and passive block is hard to explain. Studies so far, related to GBA activity, have found a dissociation between different types of GBA (spontaneous, induced, evoked, emitted) where only auditory and/or visual stimuli were used (Başar-Eroglu et al., 1996). No studies are found where GBA have been investigated in combination with the execution of a motor response. Possibly, the motoric component present in the active block may contribute to the difference of GBA between the two blocks. On one hand, our findings demonstrate similar GBA activity in frontal and parietal regions in the active block. Highly speculative, the execution of a motoric response could prevent, or at least partly, GBA from being activated. On the other hand, in the passive condition higher GBA was found in the frontal regions. From other studies there is (some) evidence that a great number of regions that evoke GBA are diffusely distributed in the whole brain and therefore it is impossible to define a unique source or structure which generates GBA (Başar-Eroglu et al., 1996). Relating this to our findings, it may be possible that in frontal regions (more) structures are situated that provoke GBA activity compared to parietal regions.

Another significance was found from analyses of the active block. In the left hemisphere, a peak of GBA was found in the baseline -300 SOA condition. However, in the right hemisphere GBA was found to be higher in the baseline condition in general (see fig. 7). Remarkable is the difference in GBA activity in the right hemisphere, where all congruencies differ as a function of SOA.

The results described above are hard to explain when we fall back on our expectations. As explained before, we expected to find greater GBA in the congruent condition compared to the incongruent- and baseline condition. While in both hemispheres a similar amount of GBA is found in the congruent condition and the incongruent condition, this is not in line with our expectations. A possible explanation for the findings in the right hemisphere, where a trend in GBA activity is found between the two SOA conditions, can be related to the time necessary to prepare a motor plan. Namely, as explained in the introduction it takes 300ms to complete a motor-translation evoked by a (auditory/visual) stimulus (Pizzamiglio et al., 2005). So, in the -300 SOA condition the auditory cue is fully translated into a motor-plan, which is not the case in the -100 SOA condition. Therefore, it might be that a more accurate comparison can be accomplished between the auditory and the imperative stimulus in the -300 SOA condition. This comparison may result in a more defined GBA in the -300 SOA condition compared to the -100 SOA condition. The difference in GBA activity between the congruent and incongruent condition in the -300 SOA condition, which cannot be found in the -100 SOA condition, contributes to this idea.

Conclusion

Before we draw any conclusions about our findings it is important to point out our exploratory goal of this study. Next to investigating the presence of the congruency effect in music we wanted to see if our design is capable of demonstrating the presence of interesting trends of results that makes it worth to proceed into a more extensive investigation. Because of the small numbers of participants, it is impossible to define stable interpretations. Consequently, all interpretations should be taken with care.

In our study, we found indications for the congruency effect, as indicated by the N400-component (Kutas and Hillyard, 1980, Brown and Hagoort,1999), to be present in music. Studies so far only used music related stimuli in combination with stimuli related to language (Daltrazzo, 2009; Koelsch, 2008). In our study we used very simple, music related stimuli from single notes. We found, by presenting (in)congruent auditory and visual stimulus-pairs to professional pianists, trends of the N400 indicating the presence of the congruency effect in music.

Furthermore, in our study we focused on the presence of GBA activity which is found to be reflecting synchronized oscillating networks formed by disparate neuronal networks (Başar-Eroglu et al., 1996). GBA activity has also been related to multi-sensory object processing (Yuval-Greenberg et al., 2007). In these studies only photographs of natural objects and environmental sounds of natural objects were used. So far, no studies have been investigating the relation between GBA and processing multi-sensory stimuli related to music. We found some indications for the presence of GBA in multi-sensory processing of music, by using very simple, stimuli from single music notes.

In this study, we provided basic findings related to visuo-motorics and the congruency effect in music, which may incite further research. Next to our contribution, further research is necessary for expanding the insight in the multidimensional cognitive activity of perception and action, related to music.

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