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SNARC-LIKE EFFECTS FOR VISUAL AND AUDITORY MUSICAL STIMULI: THE RELATION BETWEEN SPACE AND DIFFERENT MUSIC PARAMETERS

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DOTTORANDO
VALTER PRPIC

COORDINATORE
PROF. TIZIANO AGOSTINI

SUPERVISORE DI TESI
PROF. TIZIANO AGOSTINI

CO-SUPERVISORE DI TESI
PROF. DRAŽEN DOMIJAN

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Dedicated to

Дзера Кусова

"Non confondere mai l'insolito con l'impossibile."

"Never mistake the unusual for the impossible"

- Paolo Sorrentino -

ABSTRACT

This thesis aimed to investigate the spatial association for different music parameters through four experimental studies, showing consistent SNARC-like effects for note height, note value/duration, music tempo and pitch height.

Visually presented notes on the stave showed relatively low/high notes to be associated to left/right response key-presses in musicians with formal education, while no signs of such an association were found in amateur musicians. A further experiment revealed that the direction of the association is constant among musicians and is not influenced by the disposition of notes on the keyboard of specific instruments (i.e., piano and flute).

Note value/duration showed to be spatially coded when duration magnitude was processed directly, while no such evidence was revealed in the order-irrelevant task. The direction of the association surprisingly revealed a reversed pattern from the expected one, namely large duration values were coupled with left key-presses, while the opposite was true for small duration values. This evidence seems to support the predominance of over-learned ordinal sequences as opposed to stimuli's magnitude, in the spatial association effects.

Auditory presented beat sequences showed to be spatially coded even in non musicians. Indeed, participants revealed a left/right key-press advantage for relatively slow/fast music tempo when tempo processing was mandatory, while no evidence of a spatial association appeared in the order-irrelevant task (i.e., timbre judgment). Evidence of a spatial association in non musicians suggests that experience with tempo is widespread among the population and its influence overcomes the music domain.

The spatial association for pitch height was assessed through an alternative response coding to close and far key-presses, instead of the classically used left-right key-presses. Results showed a relative advantage for close responses to middle-range pitches with piano timbre, suggesting a linear representation for piano tones. However, further investigations are needed to certainly discriminate predictions based on different theoretical accounts.

Overall, this thesis provides a complete review of the spatial association for musical stimuli, showing that various parameters of music share many features in common with numbers, ordinal sequences and other magnitudes. Furthermore, music showed to be an interesting domain for investigating more general properties that require interactions among time, space and quantity.

RIASSUNTO

Questa tesi si pone l'obiettivo di studiare l'associazione spaziale per diversi parametri musicali attraverso quattro studi sperimentali, dimostrando consistenti evidenze di effetti simil-SNARC per l'altezza delle note, il valore/durata delle note, il tempo musicale e l'altezza tonale.

Le note, presentate visivamente sul pentagramma, hanno indicato un vantaggio nella risposta con il tasto sinistro/destro per le note gravi/acute in musicisti che hanno svolto studi formali, mentre non ci sono state evidenze di quest'associazione nei musicisti amatoriali. Un esperimento successivo ha rivelato che la direzione dell'associazione è costante tra i musicisti e non è, dunque, influenzata dalla disposizione delle note in strumenti specifici (nel nostro caso, pianoforte e flauto traverso).

Il valore/durata delle note ha dimostrato di essere codificato spazialmente quando veniva richiesto un processamento di tipo esplicito, mentre non ci sono evidenze in proposito nel compito indiretto. Sorprendentemente, la direzione dell'associazione ha mostrato un andamento inverso rispetto a quello atteso, ovvero valori di durata maggiore erano associati a risposte con il tasto sinistro, mentre l'opposto avveniva per valori di durata minore. Quindi, negli effetti di associazione spaziale, ciò sembra supportare la preponderanza della direzione di apprendimento nelle sequenze ordinali rispetto al valore intrinseco della magnitudo degli stimoli.

Anche le sequenze acustiche di battiti hanno dimostrato di essere codificate spazialmente, perfino in soggetti non musicisti. Infatti, i partecipanti hanno evidenziato un vantaggio nella risposta con il tasto sinistro/destro per tempi musicali lenti/veloci quando veniva loro chiesto di elaborare esplicitamente il tempo musicale, mentre non sono state trovate tracce di un'associazione spaziale nel compito indiretto (giudizio sul timbro). L'esistenza di un'associazione spaziale nei non musicisti suggerisce che l'esperienza con il tempo sia largamente diffusa nella popolazione e che la sua influenza prevarichi il puro dominio musicale.

L'associazione spaziale per i toni musicali è stata investigata con una codifica alternativa dei tasti di risposta, ovvero "vicino" e "lontano" rispetto alla classica codifica

"sinistra/destra". I risultati mostrano un vantaggio per le risposte eseguite con il tasto "vicino" per i toni intermedi con timbro di pianoforte, indicando una possibile rappresentazione lineare, piuttosto che dicotomica, per i toni del pianoforte. Ciononostante, ulteriori indagini sono necessarie per discriminare con maggiore certezza le previsioni derivanti dalle diverse teorie esistenti in quest'ambito.

Concludendo, questa tesi fornisce una complessa panoramica sul fenomeno dell'associazione spaziale degli stimoli musicali, dimostrando come diversi parametri musicali presentino caratteristiche comuni con i numeri, le sequenza ordinali ed altre tipologie di magnitudo. Inoltre, il dominio della musica ha confermato di essere un proficuo campo di ricerca per investigare le proprietà generali degli stimoli che richiedono l'interazione tra tempo, spazio e quantità.

"Music is the pleasure the human mind experiences from counting

without being aware that it is counting"

- Gottfried Leibniz -

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GENERAL INTRODUCTION

This thesis takes its origin from my mutual passion for both music and science, two souls that coexist in me since long time. I always played and composed music as a scientist, with method and reason. On the other hand I made my research works with the passion and the emotional involvement of a musician and an artist. In my opinion, both influences highly enriched my approach to the respective disciplines. During my PhD studies I had the great opportunity to experimentally examine how musicians and non-musicians process music, coupling in the same work both main interests. Thus, I consider myself incredibly lucky for such an opportunity and I'll always remember this experience with great joy and pleasure.

With this thesis I investigated the spatial association for different parameters of music, extending the works of Rusconi, Kwan, Giordano, Umiltà, & Butterworth, (2006) and Lidji, Kolinsky, Lochy, & Morais, (2007), which highly inspired my study. The evidence provided with the present work exceeds the domain of music cognition itself, connecting music with number, space and time processing. As Walsh (2003) proposed in the A Theory of Magnitude (ATOM) model, time, space and numbers seem to be processed through a common cognitive system for magnitude processing. Music is thus a great and powerful tool for investigating the relations among these domains, as it is highly coupled with time, space and numbers. Indeed, all these variables can be extracted and analyzed from different music parameters. The work that mostly inspired my thesis is the study of Dehaene, Bossini, & Giraux (1993), which demonstrated a strict link between numbers and space. Indeed, the Spatial-Numerical Association of Response Codes (i.e., the SNARC effect) is taken as proof of the spatial representation of numbers. In the present work we demonstrated, through several experimental investigations, that such a link exists also between most parameters of music and space.

The coupling of music with numbers and space should not seem surprising, as music and mathematics have always been considered strongly related. Indeed, there are certain mathematical structures inherent in all music elements and compositions. One of the most known ancient philosopher that noticed mathematical rules to control musical properties, such as pitch height, was Pythagoras (6th century BC). He noticed that different notes were produced, when the blacksmith struck his anvil, in relation to the weight of the hammer. Numbers, represented by the hammer's weight, rules musical tones. Another powerful example of the coupling among music tones, numbers and space is the sound produced in proportion to the string lengths. The ancients noticed that, the shortest the length of the string, the higher the pitch is produced, and vice versa. The Greeks, from which we inherited our musical notation, expressed these relations mathematically , recognizing intervals produced by multiple strings. For instance, two strings with length in relation to each other 1:2 produces an octave, 2:3 a fifth, 3:4 a fourth, etc. Thus, to have established a relationship between music, space and numbers charmed the Pythagoreans and the subject was taken up by the School of Plato and the subsequent Neo-Platonians (Hunt, 1978).

Another popular example of mathematical rules in music is the Fibonacci ratio, on which notes in the western scale are disposed. Also musical compositions and instrument structures are often based on the Fibonacci sequence and the golden ratio, as many other elements in art, architecture and nature (Sala & Cappellato, 2003). It seems like "beauty" and "harmony", in general, are ruled by precise numerical sequences and ratios.

Below are briefly exposed the main contents of each single chapter.

Chapter 1 provides a brief analysis of music theory and sound properties. In particular, the aim of this chapter is to get a clear definition of music terminology and basic music elements needed to understand the further proposed experimental studies.

Chapter 2 analyzes various elements and effects that are related in some way to the SNARC effect, such as: the mental number line, the distance and size effects, the stimulus-response compatibility effects, the Simon and the MARC effects.

Chapter 3 provides an exhaustive review on the SNARC effect's literature, analyzing the main features and properties of the Spatial-Numerical Association of Response Codes.

Chapter 4 focuses on the more prominent theories and models that account for the SNARC effect and number representation in general.

Chapter 5 analyzes the spatial association for visually presented note height on the stave. This study particularly focuses on the investigation of differences, in the spatial association, among amateur musicians and professional musicians, playing different instruments. The final aim is to verify whether the representation of notes on the stave is "abstract", thus common through musicians, or if it's influenced by the notes' disposition on the specific instrument played.

Chapter 6 focuses on the spatial association for visually presented note value/duration, investigated both through an order-relevant and an order-irrelevant task in professional musicians. Note value, as a symbolic representation of note magnitude duration, is expected to reveal an association with external space as numbers do.

Chapter 7 aims to verify the existence of a similar association for music tempo in participants without formal musical education. Here, participants were required to judge the "speed" and the timbre of a series of auditory beat sequences.

Chapter 8 provides an alternative version of the SMARC effect (Rusconi et al., 2006), coding responses to pitch height as "close" or "far" to a referent key, instead of traditionally used left-right responses. This expedient allows us to verify predictions based on the direct mapping account (Dehaene et al., 1993) and the intermediate coding accounts (Gevers, Verguts, Reynvoet, Caessens & Fias, 2006; Proctor & Cho, 2006).

Chapter 9 provides a general discussion on the evidence found in four experimental studies, aimed to investigate the spatial association for musical stimuli.

In chapters 5, 6, 7 and 8, independent studies are exposed investigating different parameters of music (i.e., note height on the musical stave, note value/duration, music tempo and pitch height). I decided to present the four studies in the article form, thus each one is inclusive of its own introduction, methods, results and discussion. This format seems mostly efficient to properly present each work and allows them to be read separately. Thus, chapters 1, 2, 3 and 4 represent a general introduction, which largely analyzes common literature and theoretical frames to the following studies. Otherwise, each of the studies' introductions will specifically focus on its most relevant literature parts. A similar idea rules also the single studies' discussions and the general discussion.

Chapter 1

MUSIC AND SOUND

1.1 MUSIC THEORY

Music theory studies how music is written and played. It analyzes the fundamental parameters of music, commonly dividing them in 7 basic elements: melody, harmony, rhythm, tone colour, form, tempo and dynamics. However, there is no unique classification of music elements and different partitions can be found in music books. For instance, White divides them in rhythm, melody, harmony and sound, with sound including timbre, dynamics and texture (White, 1976).

A different and more comprehensive list can be provided stating the aspects of sound: pitch, timbre, intensity and duration (Owen, 2000). Where, pitch includes all the aspects of sound frequency (melody, harmony, tonality, tessitura and tuning or temperament), timbre is the quality of a sound (it includes tone colour and articulation), intensity or dynamics represents the loudness or quietness of a sound, and duration includes all the temporal aspects of music (pulse, beat, rhythm, rhythmic density, meter and tempo). These fundamentals can be combined creating secondary aspects including form or structure, texture, and style.

The previously seen parameters of music are distinct elements which may be manipulated separately from the other. The term "parameter" was firstly used in music by Joseph Schilinger, though its relative popularity is due to the German scientist Werner Meyer-Eppler (Grant, 2005). This term defines better than others the characteristics of music and its physical properties, suggesting the possibility to measure and scientifically analyze them.

Analyzing music theory in details is not of fundamental importance for the aims of this study. However, a brief review of the basic knowledge of music will be useful for deeply understanding the current research. Therefore, more attention will be given to the elements that will characterize our experimental investigation, and clear definitions will be provided for the music terminology used hereafter.

1.2 SOUND

1.2.1 Sound waves

From a physical point of view, sound can be defined as a wave motion, a mechanical wave that is produced by the pressure oscillation spread through any elastic media capable of vibration. From a psychophysical position, sound can be viewed as an excitation of the hearing sense leading to the perception of the sound (Everest & Pohlmann, 2009).

The wave pressure propagates from one particle to another of the conducting media. During their propagation, sound waves cause the particles to be pressed together in some regions (compression) and expand in others (rarefaction). Sound speed depends on the medium of the sound: the greater is the density of the medium, the faster is the propagation of the sound.

The simplest sound has the form of a sine wave, a function describing a smooth and repetitive oscillation with constant amplitude and wavelength. A crest is the point on a wave with the maximum value or the upward point within a cycle, while a trough is the opposite of a crest, so the minimum or lowest point in a cycle (Figure 1).

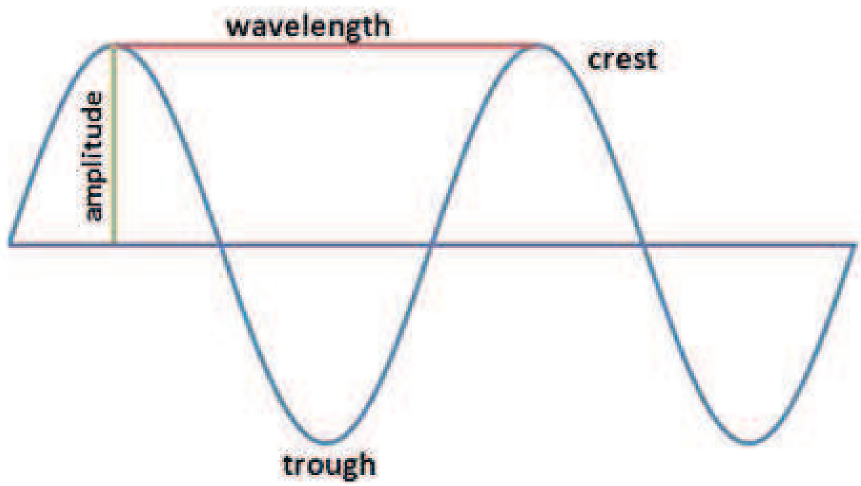

Figure 1. *Sound wave.*

Amplitude is the distance from the highest (crest) or the lowest (trough) wave points to the zero value during one wave cycle, therefore it can be positive or negative. Otherwise, a peak-to-peak amplitude is the distance between a crest and a trough.

The wavelength is the spatial period of the wave, which is the distance between consecutive corresponding points of the same phase, such as crests, troughs, or zero crossings. Wavelength is commonly designated by the Greek letter *lambda* (λ).

The Period (T) of a wave is the time it takes to complete one cycle of the wave. It's usually measured in seconds.

Frequency (f) is the number of periods per time unit and it's typically measured in hertz. One cycle per second corresponds to a frequency of 1 Hertz (Hz).

Phase, in multiple wave scenario, indicates the position of one wave relative to another. Two identical waves are "in-phase" when crests and troughs of both waves happen at the same time and "out-of-phase" when the crests of one wave meets the trough of the other.

Sound waves in music are almost always the results of many different simple waves combined together. All these simple waves form the so called complex waves. Any complex wave can therefore be reduced to its simple components, as long as it is periodic (Everest & Pohlmann, 2009).

1.2.2 Auditory sound perception

The human ear can normally hear sounds in the range from 20 Hz to 20 kHz, while frequencies from 4 Hz to 20 Hz are perceived through the sense of touch.

The amplitude and frequency of a sound wave correspond to different aspects of sound perception. Indeed, amplitude is related to the perceived loudness, while frequency determines the perceived pitch of a sound (Everest & Pohlmann, 2009). However, amplitude and frequency interact with each other when determining the characteristics of the perceived sound.

The "absolute threshold of hearing" is the minimum sound level, produced by a pure tone that can be perceived. It is represented as a function of sound pressure (measured in

Decibel, Db; it's directly related to the amplitude of a sound wave) and sound frequency (measured in Hertz, Hz). Therefore, at different frequency values, a given sound needs more or less pressure to be heard (Everest & Pohlmann, 2009).

The same interaction can be found in the equal-loudness contour (Figure 2), a measure of sound pressure over the frequency spectrum. While listening to a series of pure tones, a listener perceives a constant loudness among different frequencies but, at lower frequencies, much more sound pressure is needed to perceive the same loudness as from high frequencies (Suzuki et al., 2003).

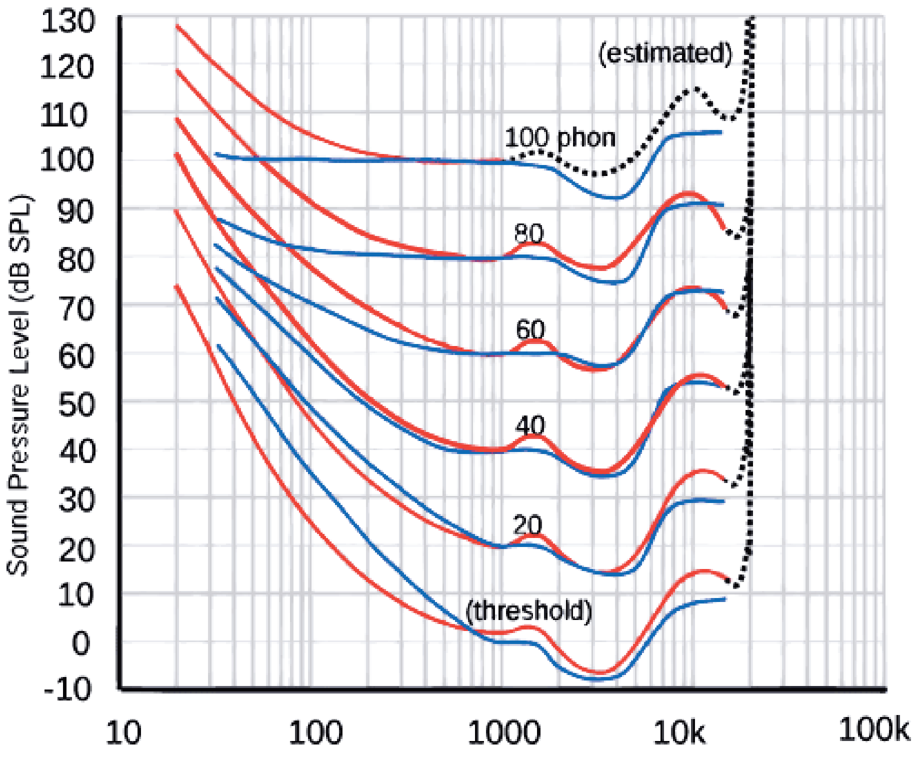

Figure 2. *Equal-loudness contour.*

1.2.3 Frequency and temporal resolution

Frequency resolution is the ability to distinguish between two tones having different frequencies. For very small differences it's impossible to perceive the difference between two frequencies, thus a listener perceives the same pitch from both sounds though they are physically different. The minimum noticeable frequency difference between two tones is called the "difference limen" (DL) or the "just noticeable difference" (JND) (Durrant &

Lovrinic, 1995). Frequency DL depends on the frequency, intensity and duration of the used tone. The DL is around 0,5% in the range 2000-3000Hz, while it gets worse for higher and lower frequencies (3% at 100 Hz). Sudden changes in frequency are detected much easier than slow changes (Roederer, 1973).

Temporal resolution is the shortest period of time over which two distinct sounds can be identified as separated. It's approximately around 2-3 ms when hearing the same sound with higher frequencies at a properly audible level. Otherwise, for sounds that differ for duration or spectral components, the temporal resolution is much longer, around 20 ms (Gelfand, 2004).

1.3 MUSIC TONES AND PITCH

A music tone is a sound played or sung at a specific pitch (Miller, 2005). It is a steady periodic sound, characterized by its duration, pitch, intensity and timbre (Roederer, 1973).

A simple tone, or pure tone, has a sinusoidal waveform, while a compound tone is not sinusoidal but still periodic. It can be described as a sum of simple tones with harmonically related frequencies (Helmholtz, 1912).

Pitch is a subjective sensation reflecting the highness or the lowness of a sound. Therefore, a higher pitched tone is a tone being higher in frequency compared to another tone, while the opposite is true for a lower pitched tone. In general, perceived pitch is nearly always closely connected with the fundamental frequency of a note. Indeed, the higher or the lower the frequency of vibration is, the higher or the lower the pitch is perceived.

The bases of the Western musical system are notes and scales. A note is a pitch having a standardized frequency. In the Western musical system, there are twelve notes, seven are indicated with the first letters of the alphabet: A, B, C, D, E, F, G, while the other five are interposed between these seven notes and are indicated using sharp (♯) or flat (♭) in relation to the rule played in the scale.

A scale is a succession of notes with a standardized criterion that depends on the theory and tradition used. In the contemporary Western musical system, notes are related to each other by a set of standardized rules called the Equal Temperament method. It's a tuning system in which every pair of adjacent notes has an identical frequency ratio. Therefore, the perceived distance between one note and its nearest neighbor note is the same for every note in the system.

At the bases of the Equal Temperament system there are three fundamental aspects: the octave, the semitone and the tone.

The octave is the distance between two notes with the same name but with a double frequency value. For instance, the standard A note has a frequency of 440 Hz. Doubling the frequency gives a value of 880 Hz, corresponding to the same A note but with a higher pitch. Usually, for indicating the octave, after the note name can be written a number reflecting its exact octave. Indeed, the 440 Hz A note is labeled as A5, while the 880 Hz A note is labeled as A6. There is thus one octave distance between A5 and A6, as A1 is one octave distant from A2, two octaves from A3, four octaves from A5, and so on. Octaves are logarithmically related (Everest & Pohlmann, 2009), as the lowest one is related to the following one by a 2:1 ratio.

Dividing the octave in twelve identical parts generates the concept of semitone, also called half step or half tone. A semitone is the distance between two notes belonging to the same octave with a $2^{1/12}$: 1 frequency ratio (one twelfth of the octave). A semitone is actually the smallest musical interval commonly used in Western tonal music (Frova, 2014).

A tone corresponds to a two semitone distance, therefore two notes distant one tone from each other have a frequency ratio of $2^{1/6}$: 1 (Benson, 2008). Tones, semitones and any frequency ratios between two notes are generally indicated with the term intervals. Tones and semitones are used to build musical scales, which are a sequence of notes related to each other by a standard succession of tones and semitones.

The chromatic scale is characterized by twelve notes, each one with a semitone distance from the neighbor notes. Otherwise, the major scale has notes related by a T, T, sT, T, T, T, sT, succession where "T" stands for one tone distance, while "sT" for one semitone distance, and the first and the last notes are one octave distant (Miller, 2005).

The intervals between the first note and the following ones are given standardized names and are characterized by fixed ratios among frequencies. Every scale pattern can start from any note, called the fundamental, giving the scale a different name. For instance, a Major scale starting from C is named C Major scale. In this scale, C is the fundamental note and the whole scale will be composed by C, D, E, F, G, A, B, and C notes. The second C is one octave higher than the first C. Every interval relates the frequencies of the notes in a fixed proportion: unison (1:1), second (9:8), third (5:4), fourth (4:3), fifth (3:2), sixth (5:3), seventh (15:8), and octave (2:1). In Minor scales (Natural minor, Harmonic minor and Melodic minor scales) the sequence of tones and semitones is different. An eight-note scale, composed of seven notes and a repeated octave, is called diatonic scale. It is composed by five tone- and two semitone intervals for each octave (Frova, 2014).

1.4 QUALITIES OF SOUND

With quality of sound of a voice or an instrument, we refer to the timbre (also called colour or tone colour). It varies widely from one instrument to another and from one voice to another. The timbre depends primarily upon the spectrum of the stimulus but also upon the waveform, the sound pressure, the frequencies and other characteristics. It makes it possible to distinguish between two or more sound sources having the same rhythm, pitch, intensity and duration (Frova, 2014).

1.5 TEMPORAL ASPECTS OF MUSIC

Temporal aspects of music are composed and strictly related one to each other.

Rhythm is made up of sounds and silences, combined together to form repeated patterns that create the rhythm itself. The fundamental basis of rhythm is due to the grouping process, which is a cognitive and not a physical factor (Berry, 1976).

The beats are the basic units of time in music; they are rhythmically organized by the time signature and defined in speed by the tempo.

Tempo is defined as the speed and pace of a piece of music. It indicates the speed of a song and the rate at which beats are repeated. Its typical measure is the Bpm (Beats per minute) that indicates, indeed, the number of beats inside a time unit (i.e., the minute).

1.5.1 Rhythm perception

Perceived tempo is determined primarily by the time between two events in an auditory stream. The time between the onsets of successive auditory events (beats or notes) is named: inter-onset interval (IOI). It is measured in milliseconds and its duration is strictly linked to the tempo value of the beats. For instance, 60 Bpm equal to an IOI of 1000ms, 120 Bpm equal to a IOI of 500ms, and so on.

The beat pulse can be perceived in a determined range of IOI. Indeed, with IOIs shorter than 100ms there is no perception of pulse and events are heard together as an unitary continuous sequence of sound (Fraisse, 1978). Otherwise, with IOIs longer than 1500ms, there are grouping difficulties and the sound is perceived as a sequence of isolated beats and, therefore, no rhythm is perceived in this condition (Fraisse, 1978).

With intervals estimation we mean the human's ability to perceive time duration. In studies in which participants had to provide an absolute estimation of the duration of a sound, perceived durations deviated constantly from the objective durations. Indeed, very short intervals tended to be overestimated, while long intervals tended to be underestimated. Judgments were mostly accurate only for durations of approximately 600ms (Eisler, 1976).

Spontaneous tempo is an experimental measure corresponding to the pace at which persons spontaneously tap their index fingers. They are asked to tap at their own like, at the rate they consider not too slow nor too fast (Stern, 1900). Tap rates for spontaneous tempo range from IOIs of 380ms to 880ms (Fraisse, 1982; McAuley, Jones, Holub, Johnston & Miller, 2006), with mean values laying around 600ms (Fraisse, 1982). Other results show a bimodal distribution, with modes around 272ms and 450ms (Collyer, Broadbent & Church, 1994).

Individual differences tend to be very large (from 200ms to 1200ms) but very stable within the same participant's production (McAuley et al., 2006).

Preferred tempo refers to the rate of a series of beats that is judged to be neither too slow nor too fast. Like for spontaneous tempo, there are great individual differences but the average value is near to 600ms.

1.6 WRITING MUSIC

1.6.1 Pitch

The basic element of the musical notation is the stave or staff, a structure composed by five horizontal lines and four intervening spaces, upon which musical symbols are placed. Each of the five lines and four spaces correspond to a note of the diatonic scale. The clef, a musical symbol placed in the beginning of every score, assigns specific notes to the lines and spaces.

There are different kinds of clefs. For instance, the most popular is the treble clef, which assigns the G note to the second line and, consequently, the corresponding notes to every other line and space. Lower pitched notes are drawn on lower lines and spaces, while the higher pitched notes on the higher lines and spaces. If needed, more lines and spaces can be added above or below the five default lines. These are called ledger lines.

Notes are written as circles and often present a vertical stem and a flag on it. As the position on the stave represents the pitch height, the notes' shape depends on their duration value. Because notes placed on the staff represent only natural notes (without flats or sharps), more symbols are needed to indicate some semitone increments. These symbols are called accidentals. There are three main accidentals: sharps (♯), flats (♭) and naturals (♮).

They can be placed straight before the note which they refer to or just after the clef. In the latter case, they take the name of "key signature".

The key signature is a series of flats and sharps, placed on specific lines or spaces of the stave, indicating that all the notes corresponding to the altered spaces and/or lines has to be considered a semitone higher or lower depending on the corresponding sharp or flat.

Indeed, sharps increase the related note by a semitone, while flats decrease the corresponding value by one semitone. Otherwise, naturals are used to indicate that a note, whose value is charged by the key signature, has to be performed as if there was no sharp or flat assigned to it (Rattalino, 1997).

1.6.2 Temporal aspects

A measure, or bar, is a segment of time containing a determined number of beats with a given duration. Measures are represented on the staff by the space between two vertical lines, indicated with the term "bar-lines". These two lines connect the first and the fifth line of the stave. There are different kinds of bar lines: simple bar-lines, double bar-lines, and bold double bar-lines.

Tempo is written at the beginning of the music sheet with a note symbol followed by an integer value. The note symbol indicates which note duration has to be considered as the rhythmic base value, while the numbers show how many of the former notes should be played in one minute. For instance, ♪=120 means that 120 quarter notes should be played in one minute, therefore every quarter note in the given musical piece should last for half a second.

A note is represented with a symbol on the staff, it's composed by the note head, the stem and the flag. The relative note duration is indicated through variations of the colour/shape of the note's head, the presence of a stem and the number of flags. The most commonly used note values are: whole notes, half notes, quarter notes, eighth notes, sixteenth notes and thirty-second notes (Figure 3).

Every note is related to the others by fixed duration properties. For instance, a whole note lasts as much as two half notes; an half note lasts as two quarter notes, and so on. Moreover, note duration can be modified by adding a dot after it, adding to its duration half of its original value.

Notice that, note duration is relative and it gives no indication regarding its physical time duration. This information is provided by the tempo of the piece, while how many notes can exist in one bar is indicated by the time signature.

A rest is an interval of silence in a musical piece and, as for notes, its duration is represented with different symbols.

Time signature is represented by two numerals, one above the other, placed right after the clef. The lower numeral indicates which note value represents the piece beat, while the upper numeral indicates how many beats exist in a bar. For instance, 2/4 means that the base beat of the musical piece is the quarter note and that every bar can contain two quarter notes, or any combination of note values which sum corresponds to two quarter notes (Rattalino, 1997).

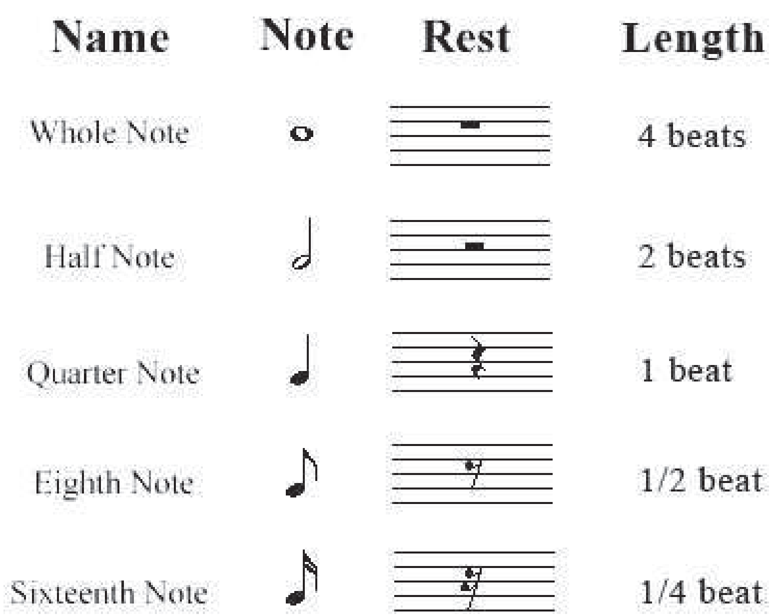

Figure 3. *Music notation.*

Chapter 2

THE SNARC EFFECT FORERUNNERS

2.1 THE MENTAL NUMBER LINE

The first visuo-spatial number representation was proposed by Galton in the "Visualized numerals" (Galton, 1880a, 1880b). In his studies he asked participants to describe how they represent numbers, showing some converging results toward similar visuo-spatial representations. The introspective methodology used by Galton cannot provide strong scientific evidence about the spatial representation of numbers but shows a generalized tendency to imagine numbers as coded in space. Some participants, in Galton's studies, reported to imagine numbers as positioned on a continuous line with a left to right orientation. This line, representing small numbers on the left and right numbers on the right, was named by Galton "Number Form" but represents what we usually call the "Mental Number Line" (MNL) (Figure 4). Galton's studies reported different shape, colour, size and position of this mental representation but, as the author stated, its individual characteristics remained constant during participants life. Moreover, these numerical representations were automatically activated in the presence of any number, being it written, heard or imagined. The "Number Form" seems to emerge during infancy, without relationship to any number and calculation teaching method. Galton estimated that such representation exists in about 1 out of 30 adult males and 1 of 15 adult females (Galton, 1880a, 1880b).

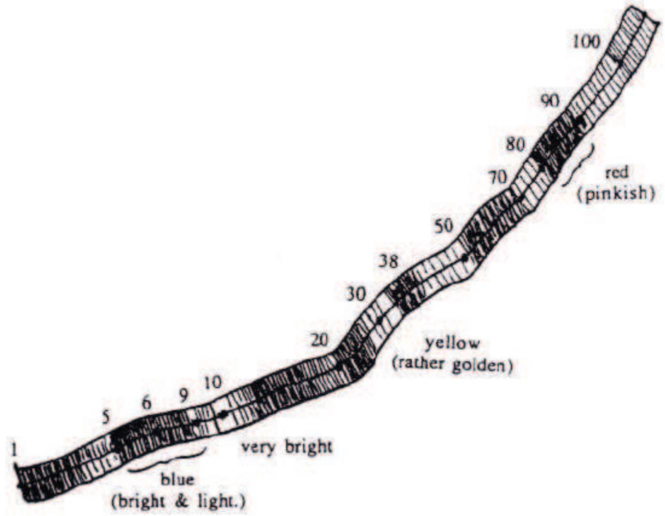

Figure 4. *Galton's mental number line.*

Bertillon (1880, 1881) reported similar evidence, also showing that some participants reported similar visuo-spatial representation for months of the year and days of the week (Bertillon, 1882). Despite Galton's and Bertillon's studies were not considered in the psychological debate for almost one century, in the last decades the interest in numerical representation and in the MNL became again of great interest for the scientific research. Seron, Pesenti, Noël, Deloche, & Cornet (1992) provided new evidence to Galton's work on the "Number Form". As stated by the authors, 14% of the population has a conscious experience of the MNL.

2.2 DISTANCE AND SIZE EFFECTS

The Distance Effect is found when participants are asked to compare symbolic and non-symbolic numerical stimuli on the basis of their relative magnitude. A difference in RTs and accuracy is found, with faster and more accurate responses when the numerical distance between the stimuli is relatively larger, and slower and less accurate responses when the numerical distance is relatively smaller (Moyer & Landauer, 1967). For instance, a comparison between the numerical couple 1 and 4 (3 units distance), and 1 and 2 (1 unit distance) is easier and faster for the first couple.

The Size Effect is another typical effect found when participants are asked to compare numerical magnitudes. Comparing numbers is more difficult the larger these numbers are in the numerical size, even when their relative distance is held constant (Moyer & Landauer, 1967). Therefore, responses are faster and more accurate when comparing 2 and 4 (2 units distance) rather than 7 and 9 (2 units distance).

Both effects were replicated with different kinds of stimuli, like Arabic digits (Banks, Fujii & Kayra-Stuart, 1976; Buckley & Gilman, 1974; Parkman, 1971), sets of dots (Buckley & Gilman, 1974) and object size (Woocher, Glass & Holyoak, 1978; Cohen Kadosh & Henik, 2006).

Some theories on the Distance Effect suggest that numbers may be encoded analogically on a mental map called "mental line" (Moyer & Landauer, 1967; Buckley & Gilman, 1974). Therefore, numbers that are closer on the mental number line share more representational characteristics than those that are distant. Being closer and, therefore, sharing more common characteristics, they lead to greater difficulties in distinguishing numerical magnitude. These difficulties lead to slower RT and less accurate responses for closest numbers.

Both Size and Distance Effects suggest that the MNL become more compressed as the numerical magnitude grows. This compression activates also the close magnitudes to the numerical target, making the comparisons more difficult. Conversely, with small magnitudes the activation of the target number is more precise because of a greater distance between numbers on the MNL. This leads to faster and more accurate magnitude comparisons. Therefore, some authors strongly argue in favour of a logarithmic compression of the MNL (Dehaene, 2001; Nieder & Miller, 2003; Dehaene, 2003) even if the debate remains still open.

2.3 STIMULUS-RESPONSE COMPATIBILITY EFFECTS

Stimulus-response compatibility (SRC) regards the mapping of stimuli to responses and is a major factor affecting the response selection stage. SRC refers to the fact that some tasks are easier or more difficult depending on the particular sets of stimuli and responses that are used or the way they are paired. Fox example, using a set of digits as stimuli, a particular digit can be paired easily with its own name as a response than, for instance, with the name of a city. Moreover, it's more difficult to pair the same digit with another digit's name rather than to its own or a city name. SRC effects occur over a wide range of stimuli and responses, and encompass a large number of different tasks, suggesting to be a general mechanism of the cognitive system (for a theoretical account see Kornblum, Hasbroucq, & Osman 1990).

The most largely investigated SRC effects are those involving spatial compatibility. Fitts and Seager (1953) firstly paired different spatial stimuli sets (three spatial combinations of points) with different spatial response sets (three spatial combinations of arrows) obtaining nine S-R ensembles, involving variations of the spatial pattern of stimuli and responses. Participants were tested in an eight-choice situation revealing higher RTs and accuracy for ensembles with equivalent stimuli and response spatial configurations. Fitts and Deininger (1954) addressed the question of element-level compatibility in a second classical experiment. In that study, a set of eight spatially defined responses was combined with three different stimulus sets that varied in their mutual correspondence. Authors demonstrated that choice reaction times are shorter when both stimuli and responses are mapped to corresponding spatial locations than to non-corresponding locations.

Another demonstration of the spatial S-R compatibility effects is provided by Broadbent and Gregory (1962). Authors showed that, if participants responded to left or right stimuli by pressing a left or right key, left responses are faster to left stimuli then to right stimuli, while the opposite is true for right responses.

2.4 THE SIMON EFFECT

Spatial S-R compatibility can affect the performance in a task even when the stimulus location is irrelevant, a phenomenon known as the Simon effect (Simon & Rudell, 1967). For instance, if participants have to respond with a left or right key to non-spatial attributes of a stimulus that appeared randomly on the left or right side, responses are faster if stimulus and response positions correspond than if they do not.

In the classic experiment of Simon and Rudell (1967), the auditory words "left" and "right" were presented to the participants through separated left and right speakers. They had to respond to the heard word meaning using a left or a right key, while ignoring the presentation location. Results revealed that participants were not able to ignore the stimuli location, showing faster RTs when stimuli location, word meaning and response location corresponded.

Craft and Simon (1970) showed that the Simon Effect exists also in the visual modality. Stimuli were presented both monocularly or binocularly through a modified stereoscope. In the monocular condition, a light was presented in the right visual field to the right eye or in the left visual field to the left eye. Otherwise, in the binocular condition, two red or green lights were presented at the same time, one in each visual field. Participants had to respond with a right-hand key to the green light and with a left-hand key to the red light, or vice versa. Evidence revealed a clear Simon Effect, as responses were faster in the corresponding (right stimulated eye/right-hand responses, left stimulated eye/left-hand responses) than in the non-corresponding trials. A comparison of monocular and binocular RTs indicated that the Simon Effect was primarily due to the occurring interference in the incompatible conditions (e.g., right-hand key, left eye stimulation) than to the compatible one (e.g., right-hand key, left eye stimulation).

The Simon Effect has also been obtained with other relevant stimulus dimensions, like letters (Proctor & Lu, 1994) and geometric forms (Nicoletti & Umiltà, 1989). Moreover, the effect was also assessed in the vertically aligned arrangement of stimuli and responses (Hedge & Marsh, 1975).

2.5 THE MARC EFFECT

The MARC effect was firstly investigated by Willmes and Iversen (1995). They obtained the basic MARC effect which consists in faster responding with the right hand to even numbers and with the left hand to odd numbers, than to the opposite mapping condition. Berch, Foley, Hill and Ryan (1999), further explored the phenomenon and found that the effect was absent for children in Grade 2, 3 and 4 but present for those in Grade 6 and 8, concluding that the MARC effect is due to linguistic markedness. Although, evidence suggests that the MARC effect may be larger for digit words than for Arabic numbers, further supporting the linguistic markedness account (Nuerk, Iversen & Willmes, 2004). It consists in the correspondence of the unmarked (even) and marked (odd) verbal codes with the unmarked (right) and marked (left) response codes leading to better performance.

Chapter 3

THE SNARC EFFECT

In the previous chapter, we provided some evidence suggesting the existence of a relation between numbers and space. Galton (1880a, 1880b) firstly investigated the spatial representation of numbers, showing that a consistent sample of the population reports such visuo-spatial representation. Thus, he proposed that numbers could be represented along a mental line with different shape and colour features. After the research done by Galton, this issue was not raised anymore for a long time. Just in the last decades the spatial representation of numbers came back to the limelight and some recent investigations confirmed Galton's (1880a, 1880b) findings (Seron et al., 1992). In the meantime, just anecdotic reports were collected suggesting a link between mathematical abilities and spatial skills. Great mathematicians and physicians, like Albert Einstein, emphasized the use of visuo-spatial imagery for developing their mathematical theories and ideas (Fias & Fischer, 2005).

A first significant step was taken by Dehaene, Dupoux and Mehler (1990) using a mental chronometry approach. Participants were required to perform a number comparison task, classifying numbers as "larger" or "smaller" than a fixed reference standard by pressing a left or right response key. Results showed a distance effect (i.e., faster responses for numbers far from the reference and slower responses for numbers close to the reference). The response mappings were counterbalanced between participants thus, half of them responded with a left key-press for small judgments and with a right key-press for large judgments, while the other half did the reverse. Surprisingly, the authors reported an unexpected phenomenon. The group assigned to the first mapping (i.e., left key-press "small", right key-press "large") were considerably faster and more accurate than the other one.

A few years later Dehaene, Bosini and Giraux (1993) decided to deeply investigate such an "odd" phenomenon. They asked participants to perform a parity judgment task thus, to decide whether a single number was odd or even, by using a left or right key. Authors replicated their previous results, revealing faster left-hand responses to small numbers and faster right-hand responses to large numbers. Dehaene and colleagues (1993) named this association between numbers and left-right coordinates: the SNARC effect (i.e., Spatial-Numerical Association of Response Codes).

In the following paragraph we will analyze in more detail the findings provided by Dehaene et al. (1993) in their innovative work, named: "The Mental Representation of Parity and Number Magnitude".

3.1 THE MENTAL REPRESENTATION OF PARITY AND NUMBER MAGNITUDE

In the original work by Dehaene et al. (1993), authors didn't reduce just to prove the existence of an association between small number magnitude/left key-press and large number magnitude/right key-press, otherwise they provided an exhaustive investigation of the phenomenon across nine experiments. In the first experiment, participants were required to classify Arabic digits ranging from 0 to 9 as odd or even. They had to press a left response key with their left hand for odd numbers and a right response key with their right hand for even numbers in one experimental block. In the other block, the assignment was reversed within participants. The order of the blocks was counterbalanced between participants. Thus, Dehaene and colleagues definitively proved the SNARC effect with single digit Arabic numbers.

In the second experiment, participants were required to judge the parity status of two-digit Arabic numbers ranging from 10 to 99, failing however to show a significant SNARC effect. Resulting evidence was compatible with a decomposition model and with a strategy of selective processing of the unit digits.

In the third experiment, two numerical intervals, ranging from 0 to 5 and from 4 to 9, were tested in separate blocks. The SNARC effect was replicated in Experiment 3, showing that this effect depended only on the relative magnitude of the target stimuli within the tested numerical interval. Indeed, the numbers 4 and 5 were preferentially associated to the right or the left key-presses when they were the largest (0-5 interval) or the smallest (4-9 interval) of the interval list respectively.

In the fourth experiment, Dehaene et al. (1993) tested letters of the alphabet in both consonant - vowel and ACE versus BDF classification, showing no spatial associations. Authors concluded that the SNARC effect is specific to numerical stimuli, a claim that has been reversed by Gevers, Reynvoet and Fias (2003) further investigating letters of the alphabet and months of the year.

In the fifth experiment, a group of left-handed participants performed parity judgment with single digits (range 0-9), showing no major differences with right-handed participants of the first experiment. In the sixth experiment, right-handed participants had to respond with their hands crossed, revealing an accentuated rather than diminished or reversed SNARC effect. This experiment partially rules out a simple hemispheric interpretation of the SNARC effect, a hypothesis that has been further investigated in the following experiment.

In the seventh experiment, Iranian participants (who write from right to left in their native language) were tested with both east Arabic digits 0-9 and Arabic digits 0-9. A reversed direction of the SNARC effect would indicate an influence of the writing system in the number magnitude representation. It would also dismiss the hemispheric lateralization hypothesis, as both Iranian and French participants presumably have the same pattern of hemispheric dominance. The SNARC effect was significantly different from Iranian and French participants; however there was no evidence of a complete reversal of the direction of the association. Individual analyses were designed to assess the possibility of interindividual differences as the explanation for such results. Indeed, the number of years elapsed since their arrival in France (*arrival* variable) and the age of acquisition of a second language (*acqui* variable) predicted the direction and amplitude of the SNARC effect in both east Arabic and Arabic notation, respectively. In sum, left-to-right versus right-to-left writing has a significant influence on the direction of the SNARC effect.

In the eighth experiment, normal versus mirror-image verbal numbers were tested. Number words were written in French (e.g., zéro, un, deux, ...) and the same stimuli were reversed in the direction (left-right) in the mirror-image condition. Experiment 8 revealed a significant SNARC effect with both normal verbal and mirror-image verbal numbers. Overall the SNARC effect was weaker with verbal than with Arabic numbers and no reversal SNARC was revealed in the mirror-image condition.

In the ninth experiment, both Arabic and verbal numbers (0-19) were tested in a within-subjects design. The aim was to assess whether the parity judgment times would be parallel with both notations and whether the SNARC effect would be weaker in the verbal compared with Arabic notation. These considerations have considerable implications for models of number processing. Results show that parity judgment times were largely independent from the particular number notation used as an input, supporting the idea that there is only one mental representation of numbers from which parity information is retrieved. Moreover, a SNARC effect was found in the Arabic but not in the verbal notation. This finding suggests that the representation of number magnitude or number line is automatically activated only by Arabic number notation.

In conclusion, Dehaene et al.'s (1993) work shows that number magnitude is automatically accessed during parity judgments, even if number magnitude is irrelevant to the task. Target number magnitude has a strong effect on participants' RTs, by facilitating responses to one side of space relatively to the other. Furthermore, the SNARC effect bears some similarities to the classical Stroop and Simon effects (Simon & Rudell, 1967; Stroop, 1935).

3.2 A STATISTICAL APPROACH TO THE SNARC EFFECT

The SNARC effect can be expressed as a statistical interaction between number magnitude and response side in the external space. As stated by the mental number line hypothesis, the SNARC effect reflects an association between the number position on the mental line and the position of the response key-press, therefore statistical regression analysis (Fias, Brysbaert, Geypens & d'Ydewalle, 1996) has been traditionally used to assess more effectively such a spatial association. Specifically, the difference in RTs (dRT) for right-key minus left-key responses shows positive values for small numbers and negative values for large numbers. To statistically capture this negative correlation between numbers and space, dRT can be regressed on number magnitude for each participant and the slope coefficients tested against zero (Lorch & Meyers, 1990).

Fias and Fischer (2005) discussed several advantages related to this regression-base analysis of the SNARC effect. Firstly, the presence of the SNARC effect is judged by a main effect rather than by the presence of an interaction between magnitude and response side (i.e., does the averaged slope coefficient obtained from individual regression equations differ from zero?). Secondly, number magnitude is considered as a continuous variable. Thirdly, the regression analysis allows a straightforward quantification of the size of the effect rather than a qualitative judgment about the existence of an interaction between number magnitude and response side (i.e., the evaluation of the slope's steep). Fourthly, the effect of additional variables can easily be partialled out through statistical techniques. Fifthly, this method evaluates the linear relation for each participant, reducing the chance of misestimating the SNARC effect because of group averaging. Moreover, this allows researchers to explore the influence of individual-specific variables on the association between numbers and space (e.g., gender, handedness ...). Lastly, this technique is more flexible than other approaches because it does not require an orthogonal combination of experimental factors. This can be useful when investigating tasks other than parity judgments, which don't rely on sequential alternation between number magnitudes and response codes. Overall, Fias and Fischer (2005) highly suggest the use of linear regression for investigating the SNARC effect, even if the analysis of variance (ANOVA) has also been widely used in this field.

3.3 THE SNARC EFFECT: SOME PROPERTIES

The SNARC effect has mostly been studied in parity judgment tasks with Arabic numbers ranging from 0 to 9, however the spatial coding of numbers highly depends on the task context.

As Dehaene et al. (1993) showed in Experiment 3, the spatial association for a given number is between its relative magnitude and space. Manipulating the stimulus range (i.e., 0-5 and 4-9), authors revealed that digits 4 and 5 were associated with right responses when they were the largest digits of the range and with left responses when they were the smallest (see also Fias, Brysbaert, Geypens, & d'Ydewalle, 1996). Gevers and Lammertyn (2005) explain such property stating that the mental number line is dynamic by nature, thus the orientation of its extensions depends on the current context.

As concerns multi-digit numbers, Dehaene et al. (1993) failed to show a clear SNARC effect toward two-digit numbers in the 0 - 19 rage. However, in Dehaene et al.'s (1993) experiment, parity judgment RTs were largely predictable from the rightmost single unit digit, showing a selective attentional strategy. Differently from the parity judgment, Dehaene et al. (1990) showed a clear response side effect for two-digit numbers in a number comparison task (i.e., considerable a precursor of the SNARC effect). Moreover, Brysbaert (1995) showed in both a number comparison and naming task a significant SNARC-like effect for two-digit numbers (i.e., numbers were processed quickly when the smaller number was to the left than to the right of the compared number). Taken together, this evidence indicate that two-digit numbers are spatially coded as well as single-digit numbers. However, the question, whether single- and multi-digit numbers share the same representation (e.g., a single analogical continuous mental number line) or separated ones, remains unsolved. Similarly, a debate on whether two-digit numbers are processed holistically (Brysbaert, 1995; Dehaene et al., 1990; Reynvoet & Brysbaert, 1999) or compositionally (Fias, Lammertyn, Reynvoet, Dupont & Orban, 2003; Nuerk, Weger & Willmes, 2001) is still open. However, recent findings better support a separate representation for decade and unit magnitudes in the two-digit number processing (Ratinckx et al., 2005). For a recent review on multi-digit number processing see Nuerk, Willmes, & Fischer (2011).

Another important issue regards the extension of the number representation to negative numbers. Two possibilities are considered: negative numbers could linearly be extended to the left space as a continuum of positive numbers or, alternatively, they could be represented and processed in the same way as positive numbers. The empirical evidences provided at the moment seem to contradict each other. From one hand, Fischer's (2003b) magnitude comparison data support the idea of an extended mental number line in the left space for negative numbers, while Nuerk, Iversen and Willmes (2004) find no spatial association for negative numbers in a parity task. Finally, Fisher and Rottmann (2005) found that negative numbers were associated to the left space when digits from -9 to 9 had to be classified relatively to zero (reference value), while large negative numbers were associated to the right space in a parity judgment. Therefore, the spatial association for negative numbers may be less automatic compared to those of positive numbers, but currently there is no clear-cut evidence regarding their spatial representation.

As regarding the number format, the SNARC effect was obtained in several studies with both Arabic digits and written number words (Nuerk et al. (2004); Dehaene et al. (1993); Fias (2001)), supporting the idea of an abstract representation of number magnitude independently from number format. Finally, Nuerk, Wood and Willmes (2005) tested and consistently found the SNARC effect across different modality/notation (auditory number word, visual Arabic numbers, visual number word and visual dice pattern), thus proving that the association between number magnitude and space is amodal.

Generally speaking, the SNARC effect seems to increase due to the increase of response latencies (i.e., the longer the time to select a response, the stronger the impact of number magnitude producing the effect. Because longer response latencies cause stronger activation of magnitude representation, longer response latencies to numbers near to the numerical standard can cause categorical shape of the SNARC effect in magnitude classification tasks. Furthermore, the spatial-numerical association was found to be stronger in tasks involving semantic number processing (e.g., parity judgment) than in non-semantic tasks (e.g., colour discrimination)(Wood, Willmes, Nuerk & Fisher, 2008).

3.4 THE SNARC EFFECT FOR NON-NUMERICAL STIMULI

In the original study about the SNARC effect, Dehaene et al. (1993) firstly tried to assess whether the spatial association works not only for numbers but even for non-numerical stimuli that are sequentially ordered (e.g., months of the year, days of the week and letters of the alphabet). In Experiment 4, they found no reliable association between letters of the alphabet and external space, concluding that the SNARC effect regards only numbers. However, Gevers et al. (2003) provided a statistically more powerful study that revealed a consistent SNARC-like effect for both letters and months of the year. Therefore, SNARC is not a unique effect of number magnitude but it appears also for non-numerical ordered sequences, thus shared representation probably exists for both features. This claim is supported by Marshuetz, Smith, Jonides, DeGutis & Chenevert, 2000) findings, in which common brain areas were engaged in processing both non-numerical ordinal attributes and numbers.

In the last decade, the SNARC effect was extended to several non-numerical magnitudes such as physical size (Ren, Nicholls, Ma, & Chen, 2011), luminance (Fumarola, Prpic, Da Pos, Murgia, Umiltà, & Agostini, 2014), stimuli duration (Vallesi, Binns, & Shallice, 2008), time flow (Santiago, Lupiáñez, Pérez, & Funes, 2007) and many others. Even musical attributes, such as pitch height (Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2006; Lidji, Kolinsky, Lochy, & Morais, 2007), revealed to be spatially organized and to produce a consistent SNARC-like effect. However, the relation between the SNARC effect and non-numerical magnitudes will be further and more deeply discussed in the following chapters. In particular, the spatial organization of different parameters of music, which is the core of this thesis, will be systematically treated adding new evidence in favor of their spatial coding.

3.5 SPATIAL FEATURES OF THE SNARC EFFECT

Regarding the spatial association for numerical and non-numerical magnitudes, a naturally raised question concerns the spatial reference used in the external space. Thus, is the magnitude information coded with respect to the body (egocentric coding) or to some non-bodily object (allocentric coding)?

Dehaene et al.'s (1993) Experiment 6 showed that the relative position of the response in space, and not the responding hand, determines the SNARC effect. Indeed, the spatial-numerical association did not reverse when participants performed parity judgment with their hands crossed. Studies involving unimanual responses provided further support to the independence of the SNARC effect from the left or right hand used. A SNARC effect was obtained both responding with two fingers of one hand (Kim & Zaidel, 2003) and pointing with one hand to a left or right button (Fischer, 2003).

Moreover, the SNARC effect does not seem to be effector specific or linked to the selection of two alternative buttons. Indeed, a spatial association for number magnitude was found in the direction of eye movement (Fisher, Warlop, Hill & Fias, 2004; Schwarz & Keus, 2004) and in a naming task (Brysbaert, 1995; Zebian, 2005). Therefore, it's quite clear that the SNARC effect is not coded with respect to specific body parts.

Bächtold, Baumüller and Brugger (1998), showed that the direction of the spatial association is not strictly deep-rooted to a long term fixed representation and, otherwise, can be easily reversed asking participants to imagine numbers as presented on a ruler (small numbers on the left, large numbers on the right) or on a clock face (small numbers on the right, large numbers on the left). Authors found a reversed association, with faster left-hand responses for small numbers and faster right-hand responses for large numbers in the ruler condition, and faster left-hand responses for large numbers and faster right-hand responses for small numbers in the clock condition.

Moreover, a study with brain-damaged patients showed that an impairment in spatial abilities can influence number representation. Zorzi, Priftis and Umiltà (2002) revealed that left hemi-neglected patients, who typically show a rightward bias in line bisection tasks, also showed a right midpoint shift in a number interval bisection task. Successively, Zorzi, Priftis, Meneghello, Marenzi & Umiltà (2006) reported that such a deficit is specific for number representation and cannot be extended to other ordinal sequences such as letter of the alphabet or months of the year.

The SNARC effect is not restricted to horizontally oriented left to right responses. Evidence for an extension of the spatial-numerical association to the vertical dimension was provided by Schwarz and Keus (2004), using saccade latencies, and by Ito and Hata (2004), using a bimanual response setting. In both studies an association was assessed between small numbers/lower space and large numbers/upper space. Moreover, the SNARC effect was also found for response positions displayed with diagonal alignment (Gevers, Lammertyn, Notebaert, Verguts & Fias, 2006). Specifically, participants responded faster for large and small numbers with upper-right and low-left responses respectively.

3.6 DEVELOPMENTAL AND CULTURAL FEATURES OF THE SNARC EFFECT

As concerns the development of the association between numbers and space, a first link was found with the correlation between visuo-spatial learning disorders and a delayed or abnormal development of mathematical abilities (Rourke & Conway, 1997). The same correlations have also been discovered in some genetic disorders, such as the Williams syndrome (e.g., Ansari, Donlan, Thomas, Ewing, Peen & Karmiloff-Smith, 2003), demonstrating the fundamental role of visuo-spatial skills in number processing.

Berch, Foley, Hill and Ryan (1999) firstly investigated the onset of the SNARC effect with parity judgments, showing that a spatial-numerical association tends to appear from the third grade. However, it might be that parity judgment was not an appropriate task to ascertain such an effect or that a spatial association might exist but not being yet automatically activated. Indeed, Girelli, Lucangeli and Butterworth (2000) found that number magnitude is automatically activated only starting from the third grade. A recent study (Galen & Reitsma, 2008) investigated the development of the SNARC effect in 7-, 8-, and 9-years-old children, as well as in adults, by using both a number judgment and a detection task. Results show that, when number magnitude was relevant for the task, a spatial association was found for all age groups while, when the number magnitude was irrelevant, only in 9-years-olds and adults there was a significant SNARC effect.

Wood, Willmes, Nuerk and Fisher (2008) provided a quantitative meta-analysis on a large number of studies, showing that there is no sign of a reliable SNARC effect unless children are approximately 9.5 years old. Moreover, they showed that the size of the association increases with age, suggesting it to be a habit acquired in and reinforced by the cultural environment and the linguistic background.

As concerns the left-to-right direction of the SNARC effect, Dehaene et al. (1993) proposed that the association reflects acquired reading habits. Authors demonstrated that the Iranian group (right-to-left reading direction) showed a different pattern in the spatial-numerical association from the French group (left-to-right reading direction), proving an influence of reading habits to the direction of the effect.

Later studies supported these conclusions, indeed Zebian (2001) found that monolingual Arabic speakers processed easily two number displays when the large number was placed on the left and the small number on the right, compared to the reversed condition. Differently from the complete reversal of the SNARC-effect found for monolingual, in a bilingual group of Arabic-English speakers, this effect tended to decrease (see also Maass & Russo, 2003).

However, these studies do not certainly demonstrate that the writing direction itself is the cause of the SNARC effect. Indeed, any correlated variable may have a decisive impact, such as: early training with number lines (Fueyo & Buschel, 1998), culture-specific exploration strategies (Dehaene et al., 1993), finger-counting habits (Butterworth, 1999, chapter 5) and daily experiences in the physical word (Lakoff & Nunez, 2000).

A demonstration that the reading/writing direction is not the only relevant variable comes from Schwarz and Keus (2004). These authors showed that, eye movements were initiated faster to the bottom (top) space when a small (large) number was centrally presented, whereas the prevision raised from the reading/writing direction should reflect the opposite association.

In conclusion, there is strong evidence in favor of culturally determined factors influencing the direction of the spatial-numerical association, however further developmental and cross-cultural investigations are needed to determine the crucial variables and their interactions.

3.7 SNARC, SIMON AND OTHER SPATIAL COMPATIBILITY EFFECTS

The SNARC effect seems to be the result of joint activation of a spatial representation of number magnitude and of specific spatial task requirements (e.g., left-right key-presses). Thus, both features share a common spatial code (e.g., left-right) and its congruent activation seems to cause the effect. From that point of view, the SNARC effect is a special instance of a spatial compatibility effect. Generally speaking, spatial compatibility refers to the fact that lateralized responses are faster and more accurate when the trigger stimulus is lateralized to the same side (Fitts & Seeger, 1953).

The SNARC effect seems to be structurally similar and, thus, a variant of the Simon effect (Simon, 1969). The Simon effect is the result of a dimensional overlap between the irrelevant stimulus dimension (location of the stimulus) and the response dimension (left/right key-press). Similarly, when performing a parity judgment, the SNARC effect is the result of a dimensional overlap between the irrelevant stimulus dimension (magnitude information) and the response dimension (left/right key-press). Note that, in the Simon effect the irrelevant stimulus dimension is explicit (position on the screen) whereas in the SNARC effect it is implicit (magnitude information). Nevertheless, in the second case, the internal number representation seems to activate a task-irrelevant spatial attribute that facilitates or interferes with the spatial processing required to respond. To consider the SNARC effect as an instance of the Simon effect, it is important to prove the automaticity of numerical information spatial coding (Fias & Fischer, 2005).

The SNARC effect has been primarily investigated with parity judgment tasks and, to a lesser extent, with magnitude comparison tasks. However, the effect is not specific to these tasks for they both require numbers to be processed in some degree. Two studies primarily showed a SNARC effect where visually presented numbers were completely irrelevant to the task. Firstly, Fias, Lauwereyns and Lammertyn (2001) found that the participants' manual responses were influenced (faster left/right-hand responses for small-large numbers) by digits used as a background upon which oriented lines or triangles were superimposed for classification. Secondly, Fischer, Castel, Dodd and Pratt (2003) showed that the mere perception of numbers causes a spatial shift of attention influencing the speed of target detection. Both these findings are a strong argument in favour of automatic spatial coding.

In conclusion, the SNARC effect expresses an overlap between the spatial representation dimension of irrelevant number magnitudes and the external space of response execution, therefore it fits the category of Simon-like effects as proposed by the Kornblum et al.'s (1990) taxonomy of compatible effects. Studying the SNARC effect within the theoretical frameworks of the spatial compatibility effects is useful to fully understand both number-specific components and its spatial coding (Fias & Fischer, 2005).

Chapter 4

THE SNARC EFFECT: MAIN ACCOUNTS, THEORIES AND MODELS

4.1 THE MENTAL NUMBER LINE ACCOUNT AND THE TRIPLE-CODE MODEL

Dehaene et al. (1993) demonstrated that in the SNARC effect, even when magnitude information is irrelevant for performing the task, an association between number magnitude and response position is observed. Authors explained this phenomenon suggesting that, during parity judgments of Arabic digits, a representation of number magnitude is accessed in an automatic way and that this representation may be connected to a spatially oriented mental number line (Restle, 1970). Therefore, the SNARC effect would be the result of a direct correspondence between this mental representation (left to right oriented mental number line) and the execution of responses in the external space. Indeed, Dehaene et al. (1993) proposed exactly that:

> *"…the representation of number magnitude is automatically accessed during parity judgment of Arabic digits. This representation may be linked to a mental number line […], because it bears a natural and seemingly irrepressible correspondence with the natural left – right coordinates of external space." (p. 394).*

The mental number line (MNL) seems to be a spatially featured analogical representation, probably with genetic origins, but culturally influenced in its orientation. (Dehaene et a., 1993; Dehaene, 1997; Dehaene, Piazza, Pinel & Cohen, 2003). It appeared to be logarithmic rather than linear and to respond to the Weber-Fechner low (Dehaene, 2003).

The Triple-Code Model (Dehaene, 1992; Dehaene & Cohen, 1995) postulates that three cardinal representations of numbers may be recruited in the number processing. The first one is a magnitude system, a non-verbal analog semantic representation of the size and the distance relations between numbers. The second one is a verbal system, in which numbers are represented lexically, phonologically and syntactically, most like any other type of word. The third one is a visual system, where numbers can be encoded as strings of Arabic digits (Figure 5).

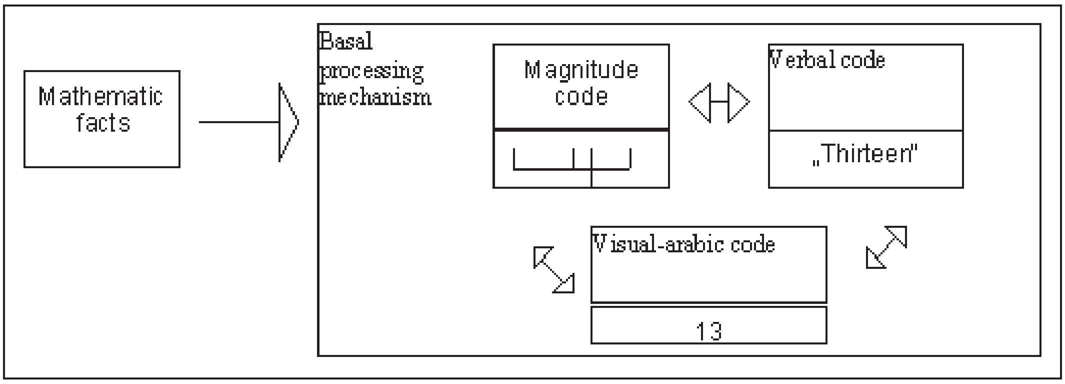

Figure 5. *The Triple-Code Model.*

Each of the three stystems constitutes the starting point for different and specific number processing activities, such as: number size comparison (magnitude system), two-digit operations (visual system) and retrieval of arithmetic facts (verbal system). The information can be excanged among the systems during further processing stages, but it will be transcoded only to the relevant modality in which further processing takes place. Therefore, access to the amodal magnitude information is necessary only for certain tasks (e.g., subitizing, estimation, approximate calculation and comparison), while it is not mandatory for other types of tasks (e.g., counting, artithmetical fact retrieval, ...).

4.2 THE POLARITY CORRESPONDENCE THEORY

An alternative theoretical account, that was proposed to explain the spatial-numerical association, is The Polarity Correspondence Principle by Proctor and Cho (2006). This theory was not specifically formulated to account for the SNARC effect or for numerical processing, indeed it can be extended to a great variety of tasks and stimuli that can be coded on a bipolar dimension. Therefore, according to the idea that binary stimuli are coded as positive (+) or negative (-) polarities, these authors explain the results obtained in different domains such as: word-picture and sentence-picture verification tasks, Simon and other stimulus-response compatibility effects, SNARC and SMARC effects in the numerical cognition, and the IAT from the social cognition literature.

The Response Compatibility is, therefore, a general principle of compatibility in binary choice tasks. This model generally assumes that, the mapping of a stimulus coded as + polarity into a response is faster when the response is also coded as + polarity than when it is - polarity, and vice versa for a stimulus coded as - polarity. In the specific case of the SNARC effect, numbers are automatically coded as either small (-) or large (+) before the activation of a spatial response and, at a later stage, this magnitude representation is associated with the corresponding response alternative (left -; right +).

Avoiding the use of a specific spatial representation for explaining the SNARC effect, this account can easily explain the spatial association obtained with non-horizontal response alignment (e.g., up +; down -). Otherwise, it is more difficult for some evidence provided with brain damaged patients (Zorzi et al., 2002). Indeed, left hemi-neglected patients show a specific deficit in the representation of relatively small digits that seem to support a linear representation of number magnitudes.

4.3 A DUAL ROUTE MODEL

A dual-route cognitive model was proposed to account for the SNARC effect, describing through different routes of information processing (i.e., conditional and unconditional routes) how number magnitude influences motor responses (Gevers, Caessens & Fias, 2005; Gevers, Verguts, Reynvoet, Caessens & Fias, 2006). According to the authors, the conditional route allows for controlling motor responses in a flexible way (e.g., by verbal instructions), while the unconditional route conveys the automatic activation of pre-existing associations between stimuli and responses.

Therefore, the SNARC effect is due to the automatic activation of the unconditional route in parallel to the conditional route. In congruent trials, both conditional and unconditional routes lead to the same association between stimuli and responses, reducing response times and increasing accuracy. Otherwise, in incongruent trials, the conditional and unconditional routes activate different associations between stimuli and responses. Since the correct response is activated in the conditional route and a concurrent response in the unconditional route, response latencies become longer and accuracy decreases. The influence of the unconditional route on motor responses becomes stronger as the time for activating the conditional route is longer. Moreover, an incorrect response may be triggered when the activation of the unconditional route is strong enough for reaching the response threshold.

The dual-route model can account for interindividual differences in the strength of the SNARC effect. Indeed, Wood, Nuerk & Willmes (2006a; 2006b) revealed the proportion of participants showing a negative slope varying between 65% and 75% (i.e., not every participant shows a significant left-to-right SNARC effect). Moreover, Cohen Kadosh and Henik (2007) suggest that the mental representation of numbers may differ across individuals and deviate from the traditionally described left-to-right representation. Thus, it may result in a high interindividual variability in the SNARC effect.

4.4 THE ATOM MODEL: A THEORY OF MAGNITUDE

Walsh (2003) analyzed the converging evidences emerging from the domains of time, space and numbers, suggesting a common processing mechanism. Thus, the author proposed the ATOM (i.e., A Theory of Magnitude) model as a conceptually new framework for re-interpreting evidence rising from traditionally separated literature. For this purpose, Walsh reviewed studies from behavioral, developmental and comparative psychology, neuropsychology, brain imaging and neurophysiology, revealing a strict link between the processing of time, space and quantity (Figure 6).

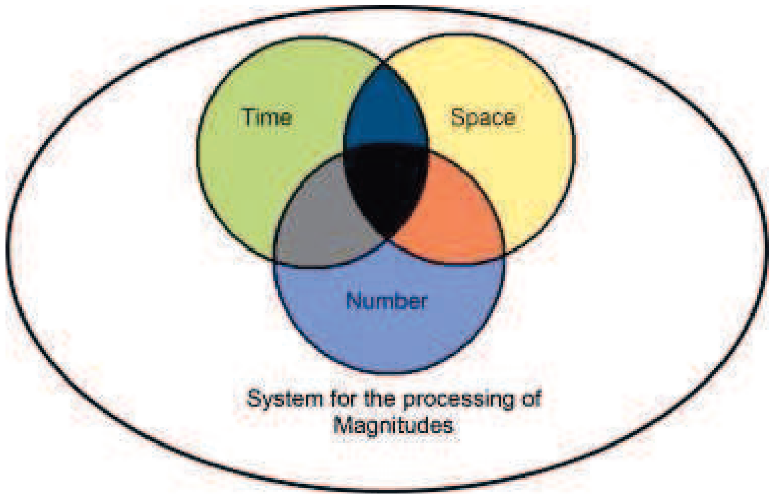

Figure 6. *The ATOM model.*

Concerning behavioral studies, a connection between space and numbers come from the evidence supporting a mental number line representation, specifically Wash mentioned the distance effect in number processing. As regards time and quantity, Brown (1997) revealed that a mental arithmetic task and a temporal task can mutually disrupt one other's performances. Moreover, also spatial factors have been proved to influence time perception (De Long, 1981; Mitchell, 1987).

The neuropsychological and brain imaging review provided by Walsh (2003) underlines the important role of the parietal cortex in the processing of space, time and quantity. Specifically, the right inferior parietal cortex (rIPC) seems to be more critical for spatial and temporal processing, whereas number processing seems to reflect bilateral activation of the IPC. In particular, the left hemisphere uses the verbal coding and is, therefore, involved in calculation, whereas the right hemisphere is active in estimation and analogical number comparison (Dehaene, 1992).

Walsh (2003) proposed much evidence from comparative psychology to sustain the existence of convergence in the processing of time, space and quantity. Specifically, non-human primate studies have shown that neurons selective for numerical quantity and temporal duration exist in areas involved in spatial processing. This evidence provides support for phylogenetic precursors of the magnitude system. Moreover, developmental studies show that infants fail to discriminate between temporal and spatial order, suggesting the use of an undifferentiated magnitude system for motor responses to changes in size, speed, distance and duration of external events (Fraisse, 1964). Walsh (2003) claims that the use of a common metric for extracting information about time, space and quantity could be highly adaptive for the infant brain.

The ATOM model gives to the parietal cortex a main function to encode different information about the magnitudes in the external world that are used in action. Thus, this system is engaged to answer the questions "how far, how fast, how much, how long and how many" with respect to specific actions (Walsh, 2003).

Summarizing, Walsh (2003) argues exactly the following points: *"space, quantity and time are linked by a common metric for action; time and quantity estimation operate on similar and partially shared accumulation principle; the inferior parietal cortex is the locus of a common magnitude system; the apparent specialization for time, space and quantity develop from a single magnitude system operating from birth; hemispheric asymmetries in time, space and number have emerged as a consequence of the fact that advanced use of number for exact calculation requires access to language in a way that spatiotemporal co-ordinate maps do not (Walsh, 2003)".*

Moreover, Walsh (2003) made a strong prediction on the SNARC effect from the ATOM model, suggesting that the spatial-numerical association should prove to be a SQUARC effect (i.e., Spatial-Quantity Association of Response Codes). Thus, not only numbers but any spatially or action-coded magnitude should reveal a relationship between magnitude and space.

For more recent reviews about the role of the parietal cortex in the magnitude representation see: Hubbard, Piazza, Pinel & Dehaene, (2005); Cohen Kadosh, Lammertyn & Izard, (2008); Cohen Kadosh & Walsh, (2009); Cantlon, Platt & Brannon, (2009).

Chapter 5

SPATIAL REPRESENTATION FOR MUSICAL NOTES IS COMMON AMONG MUSICIANS WITH FORMAL EDUCATION

5.1 INTRODUCTION

Mathematics and music have always been coupled and considered highly related. In fact, both harmonic and temporal features of music can be defined by precise mathematical ratios. As regards written music, information about note height and duration are conveyed by a symbolic language, which is made by the position of the notes on the stave and their shape. Therefore, notes for music can be considered the equivalent of numbers for mathematics. Psychological studies showed numbers to be highly coupled with space (Dehaene, Bossini, & Giraux, 1993) and music tones showed closely similar characteristics (Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2006; Lidji, Kolinsky, Lochy, & Morais, 2007). However, spatial association for written musical symbols has not been specifically investigated.

The first demonstration of an association between numbers and space was the response-side effect in number comparison (Dehaene, Dupoux, & Mehler, 1990; Hinrichs, Yurko, & Hu, 1981). When participants had to indicate whether a given number was smaller or larger than a reference number, responses to larger numbers were executed faster with the right hand than with the left hand. The reverse was true for small numbers.

A subsequent study by Dehaene, Bossini, & Giraux (1993) provided further evidence for the response-side effect (i.e., Spatial Numerical Association of Response Codes: SNARC). In evaluating a number's parity status (participants had to decide whether a given number was odd or even by using two response keys), participants were faster at judging the parity of large numbers (e.g., 9) when responses were executed in the right hemispace, whereas they were faster at judging the parity of smaller numbers (e.g., 1) when responses were executed in the left hemispace. The SNARC effect suggests that relatively small number representations are spatially compatible with the left hemispace and relatively large number representations are spatially compatible with the right hemispace. Authors explained this evidence with a left-to-right oriented mental number line (MNL). Therefore, an advantage in RT and accuracy occurs when participants have to respond in the left hemispace for numbers that are represented on the left side of the MNL (i.e., small numbers) or, vice versa, when right responses are provided for numbers that are represented on the right MNL's side (i.e., large numbers). This explanation is also known as "direct mapping account". For different accounts see: Proctor, & Cho (2006); Gevers, Verguts, Reynvoet, Caessens, & Fias (2006); Santens & Gevers (2006).

Spatial response association has been reported also for non-numerical ordered sequences. Indeed, Gevers, Reynvoet, & Fias (2003) investigated the spatial organization of two ordered sequences, namely months of the year and letters of the alphabet. Participants were asked to decide, by pressing a response key, whether a given month comes before or after June. These authors showed that the mental representation of ordinal sequences could be spatially coded. More precisely, months from the beginning of the year were responded to faster with the left hand than with the right hand, whereas the reverse was true for months towards the end of the year. Furthermore, in the experiment using letters of the alphabet, the task consisted in judging whether a given letter comes before or after “O”. Letters before “O” were responded to faster with the left hand than with the right hand, whereas the reverse was obtained for letters after “O”.

Not only numbers, months of the year and letters of the alphabet are spatially organized, it's also true for several non-numerical magnitudes such as: physical size (Ren, Nicholls, Ma, & Chen, 2011), luminance (Ren, Nicholls, Ma, & Chen, 2011; Fumarola, Prpic, Da Pos, Murgia, Umiltà, & Agostini, 2014), and time duration (Vallesi, Binns, & Shallice, 2008). With the ATOM (i.e., A Theory of Magnitude) model, Walsh (2003) proposed the existence of a common cognitive system for processing magnitudes, including space, time and quantity. According to the author, this system has its locus in the inferior parietal cortex. Walsh proposed to use the term SQUARC (i.e., Spatial-QUantity Association of Response Codes), instead of SNARC, as a more general mechanism for the spatial association of quantitative stimuli.

Zorzi, Priftis, Meneghello, Marenzi, & Umiltà (2006) further tested the hypothesis that the spatial representation that produced the SNARC effect stands not only for numerical sequences, by investigating performance of left neglect patients in bisecting numerical and non-numerical intervals. Neglect patients completed several tasks, which included the bisection of visual lines and the mental bisection of number intervals, letter intervals, and month intervals. The error pattern in the number bisection task, characterized by a rightward shift for long intervals and a leftward shift for short intervals, mirrored that of the line bisection task and confirmed the left-to-right spatial orientation of the mental number line. In contrast, the bisection of non-numerical intervals, showed a very different pattern. In the bisection of letter and month intervals, neglect patients showed a non-significant rightward and a non-significant leftward shift, respectively, of the subjective midpoint. Zorzi et al.'s results suggest that the spatial layout characterizing numerical representations constitutes a specific property of numbers rather than a general characteristic of ordered sequences. According to Zorzi et al., the association between hand and letter position would be better described as a categorical rather than a graded relation (see also Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006). That is, letters are grouped into two sets, one of which is responded to faster with the left hand and the other is responded to faster with the right hand. Differences within the two sets are very small and do not show a continuous trend.

A spatial association between stimulus and response in music has been reported by Rusconi et al., (2006). Authors explored the spatial representation of pitch height through the pairing of pitch to different response positions. In the first task, non-musicians were asked to compare the frequency of two pure tones. They had to decide whether a probe tone was higher or lower than a reference tone, by pressing one of two keys (Q and P or space bar and 6) with their left or right index finger. In the second task, non-musicians and musicians were asked to classify sounds as being produced by wind or percussion instruments, by using the same keys. Results showed that the internal representation of pitch height is spatially organized, especially in participants with formal musical education (i.e., Spatial-Musical Association of Response Codes: the SMARC effect).

Similarly, Lidji et al., (2007) replicated the previous evidence provided by Rusconi et al., (2006) with isolated tones, showing musicians to be more prone to automatically process musical stimuli. This tendency is clear when order-irrelevant task (timbre judgment) was required, to both musicians and non-musicians, in the horizontal alignment. Indeed, only musicians showed a left-effector advantage for relatively low tones and a right-effector advantage for relatively high tones when direct processing of pitch height was not required. Moreover, authors investigated whether spatial association is restricted to isolated tones or whether it extends even to melodic intervals. Very limited evidence was provided for such association, however showing a horizontal SNARC-like effect restricted to the musicians group and the order-irrelevant task.

Sloboda (1976) largely investigated the notes represented on the stave and suggested that there is a mental representation of musical notation that can be influenced by the degree of formal musical education. In a series of experiments, he examined the way in which expert musicians differed from non-musicians in their recognition of briefly exposed pitch notation. Results demonstrated that musicians were superior to non-musicians in their immediate written recall of stimuli containing more than three notes; however it was true only when the stimulus was available for 150 ms or 2 s. In a further experiment, interfering material was auditorily introduced during visual presentation of the notes: speech, tonal music (the first movement of Bruch's violin concerto) and atonal music (solo clarinet music by Boulez). The task consisted in reproducing the visual display and to ignore any background noise. Musicians' performance was not influenced by interference, whereas non-musicians' performance was surprisingly improved. In the last experiment, the interfering material consisted of paired sequences of letters and paired sequences of notes. There were three conditions: the visual task alone (as in the first experiment), the visual task with the interfering letter memory task, and the visual task with the interfering tone memory task. Participants were instructed to decide whether two paired sequences, of either letters or tones, were same or different. Results showed that musicians had a retention advantage over non-musicians in processing written notes. For a review on experimental studies in music reading see Sloboda (1984).

The aim of the present study was to investigate whether there is an association between the written representation of musical notes and side of response execution. In addition, we aimed to verify whether musical note representation can be influenced by the degree of music education (Sloboda, 1976). Therefore, two groups of participants were tested: amateur musicians and expert musicians (Experiment 1). All participants performed an order-irrelevant task that allowed us to investigate the activation automaticity of the spatial codes. Moreover, we were interested in investigating whether this association is due to an abstract representation of note height, widespread to all musicians, or whether it's influenced by the specific disposition of notes on the instrument played. Therefore, a separated group of expert musicians (piano and flute players) took part in Experiment 2.

5.2 EXPERIMENT 1

5.2.1 METHOD

5.2.1.2 Participants. Participants of both groups (amateur and expert musicians) were selected on the basis of their answer on a pre-test that was composed of questions concerning years of formal musical education, instrument played, and exams taken at a conservatory. Both groups were composed by participants playing different kinds of musical instruments (e.g., piano, violin, guitar, flute) and they were equally balanced within each group. Therefore, no specific effects due to the note disposition on the instrument were expected. All participants were able to read aloud the notes on the stave and they gave their informed consent to take part in the study.

Amateur musicians. Ten students participated, four males (mean age: 21) and six females (mean age: 25). They played a musical instrument as a hobby but they lacked formal musical education.

Expert musicians. Ten students participated in the experiment, nine females (mean age: 22) and one male (age: 27). They play a musical instrument and have taken courses and passed exams at a conservatory (mean number of years at a conservatory: 6).

5.2.1.3 Design. Experimental variables were manipulated within a repeated-measures design for regression analysis (Fias, Brysbaert, Geypens, & D'Ydewalle, 1996; Lorch & Myers, 1990). The predictor variable was the position of the note on the stave, whereas the criterion variable was the difference between reaction time (RT) of the right hand and RT of the left hand: dRT = RT (right hand) – RT (left hand). Positive dRTs indicate faster responses with the left-effector, whereas negative dRTs indicate faster responses with the right-effector.

5.2.1.4 Apparatus and stimuli. The experiment was created and controlled by the E-Prime software, version 1.2. Stimuli were displayed on a 17-inch, 16 million colour screen, with a 1024 x 768 pixels resolution (screen refresh rate: 70 Hz). The PC was a Pentium III (RAM: 128 Mb), with OS Windows 98. Stimuli were the musical notes (presented as half notes, colour: magenta), between E4 and F5 (Figure 7). Half of the stimuli were shown with the stems upwards and the other half were shown with the stems downwards. The B5 was excluded. The base of the note was elliptical (1.98° in height by 2.37° in width). The stem of the note was 3.2°. The stave measured 6.08° in height by 3.04° in width and it was centred within a white square (10° by 10°) that, in turn, was displayed in the centre of the screen against a black background.

Figure 7. *The notes on the stave.*

5.2.1.5 Procedure. The experiment took place in a quiet, dimly lit room, without environmental distractions. Participants were positioned in front of the PC. The midlines of the screen and the keyboard were aligned with the midline of the participant's body. Participants placed their head on a chinrest and were asked to position their left index finger on keyboard's key A (i.e., the leftmost key) and their right index finger on keyboard's key L (i.e., the rightmost key). The viewing distance was about 57 cm. Each trial started with a fixation cross presented for 300 ms, followed by an interstimulus interval (ISI) of 130 ms. Then the target note appeared at fixation until response.

Participants were asked to decide whether the stem of the notes was directed upwards or downwards, by pressing one of two response keys (A or L). The experiment was divided into two sessions. In the first session, participants were asked to press the right key with their right hand when the stem of the notes on the screen was upwards and the left key with their left hand when the stem of the notes was downwards. In the second session, the assignment was reversed. The order of the two sessions was counterbalanced between participants. Each of the two sessions started with 16 training trials and then each note was presented 20 times in random order. This resulted in a total of 160 trials in each session. There was a short break between the two sessions.

Both speed and accuracy were stressed in the instructions. Visual feedback was provided following response execution (i.e., “correct” vs. “wrong”). The inter-trial interval (ITI) was 1500 ms.

5.2.2 RESULTS FOR AMATEUR MUSICIANS

Data analyses were carried out with the method of linear regression for repeated measures described by Fias et al. (1996), and Lorch & Myers (1990). In the first step, for each participant the median RT of the correct responses was computed for each note, separately for left- and right-hand responses. On the basis of these medians, the dRT was computed by subtracting the median RT of the left-hand responses from the median RT of the right-hand responses. In the second step, a regression equation was computed for each participant with the position of the notes on the stave as the predictor variable. In the third step, one-sample t-tests were performed to verify whether beta regression weights of the group deviated significantly from zero.

The analysis of dRT revealed that the regression slopes were not significantly different from zero, $t(9) = -.779$, *ns*. (Figure 8). That shows the absence of a correlation between the predictor variable and the criterion variable (dRT). Thus, there was not a relative left-effector advantage in processing notes lower than B5 and a relative right-effector advantage for notes higher than B5.

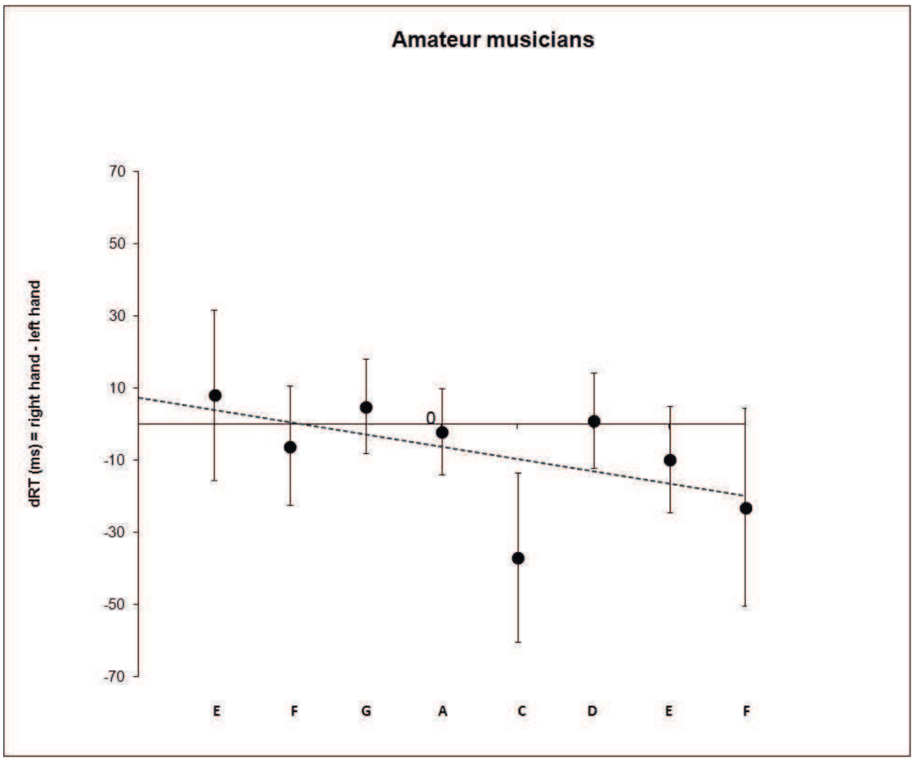

Figure 8. *Mean differences of the median RT right hand – RT left hand as a function of position of the notes on the stave in Experiment 1 for amateur musicians. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses.*

5.2.3 RESULTS FOR EXPERT MUSICIANS

Data analyses were the same as in the previous experiment. The analysis of dRT revealed that the regression slopes were significantly different from zero, $t(9) = -4.364$, $p < .05$. There was a negative correlation between the predictor variable and the criterion variable (dRT), showing a relative left-effector advantage in processing notes lower than B5 and a relative right-effector advantage in processing notes higher than B5 (Figure 9).

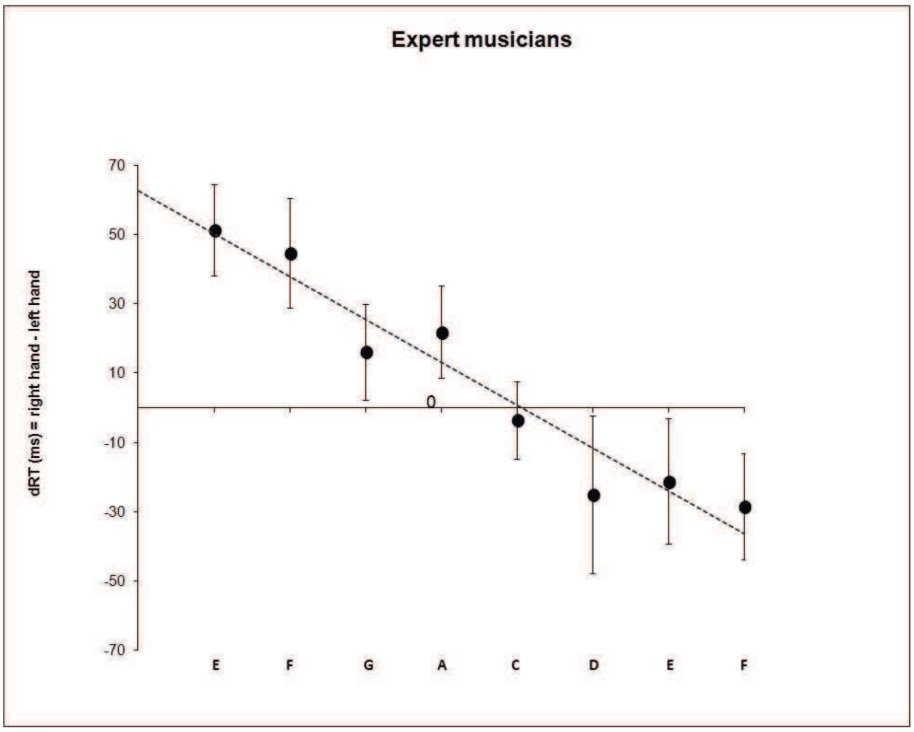

Figure 9. *Mean differences of the median RT right hand – RT left hand as a function of position of the notes on the stave in Experiment 1 for expert musicians. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses.*

5.2.4 DISCUSSION

Participants who played a musical instrument as a hobby and who had not attended a conservatory did not show a spatial representation for musical notes in Experiment 1. In particular, they did not show a left-effector advantage in processing notes lower than B5 on the stave and a relative right-effector advantage for notes higher than B5 on the stave. Apparently, a small amount of practice in reading music was not enough for producing a spatial representation for notes. Participants that play a musical instrument and have taken exams at a conservatory showed a left-effector advantage in processing notes lower than B5, which shifted to a relative right-effector advantage for notes higher than B5.

There is, thus, an association between the notes height on the stave and the spatial properties of the response. This association might be explained as a spatial representation of musical notes following a mental line oriented from left to right, where the order of notes is determined by their position on the stave. However, theoretical implications about the linear (Dehaene et al., 1993) or the categorical (Proctor & Cho, 2006; Gevers et al., 2006) nature of this spatial association are not the aim of this study.

Experiment 1 clearly showed that the association between the position of the notes on the stave and side of response execution occurs even when direct processing of note height is irrelevant to the task, just as for number magnitude in parity judgment (Dehaene et al., 1993). Moreover, the absence of this association in the amateur musicians group proves that it is certainly due to a genuine SNARC-like effect for note height and not simply to an orthogonal Simon effect (i.e., targets that are displayed above on the screen are processed faster with responses executed in the right space, whereas targets presented below are processed faster with responses executed in the left space; Bauer & Miller, 1982). Indeed, if the evidence of the spatial association in Experiment 1 were due to the orthogonal Simon effect, the same results should be displayed for both amateur and expert musicians groups, as for every kind of participant irrespective of their musical background and education.

5.3 EXPERIMENT 2

In the previous experiment, a spatial relation between musical notation and space of response execution was reported in the expert musicians group. This association was assessed with an order-irrelevant task (i.e., participants were asked to decide whether the stem of the notes was directed upwards or downwards) that doesn't require the direct comparison of the note height on the stave. The direction of the current SNARC-like effect shows a left-effector advantage in processing relatively low notes (notes positioned lower than B5 on the stave) and a right-effector advantage in processing relatively high notes (notes positioned higher than B5 on the stave). However, the direction of this association can be due to the specific instrument played by the participants rather than to a more general representation of note height. Indeed, most musical instruments display low pitched notes on the left side of the keyboard and high pitched notes on the right side. The best example of such note disposition is the piano keyboard. Moreover, besides being the most popular and widely played instrument overall, all the music conservatory students have to attend also piano exams during the course of their studies, as well as for the other instrument played. Therefore, without taking strongly in consideration the disposition of notes on the instrument played by the participants, the mixed instrument group of musicians (Experiment 1) can't solve the origin of the currently assessed spatial association. Indeed, the predominance of the low-left and high-right disposition of the notes in the experience of most musicians could be the real explanation for our results.

In Experiment 2, we will try to solve this issue by using two different groups of musicians with formal education: piano players and flute players. As previously mentioned, piano keyboards display low pitched notes on the left side and high pitched notes on the right side, moreover low pitched notes are played with the musicians left hand while high pitched notes are played with musicians right hand. On the contrary, low pitched notes on the flute are displayed on the right side while high pitched notes are displayed on the instrument's left side (Figure 10). Moreover, also the hands used for playing notes on the piano are reversed in the flute (i.e., right hand used for playing low pitched notes and left hand used for playing high pitched notes). Therefore, if the spatial association for music notes is due to the disposition of notes on the specific instrument played, rather than to a universal abstract representation spread among all musicians, we expect to find an opposite association direction in piano and flute players. Or, at least, some difference in the association's strength should be found. However, it's almost impossible to find "pure" flute players in music conservatory because piano exams are mandatory for all musicians. In any case, choosing flute as a main instrument requires spending most part of the time practicing on it.

An interesting example of how spatial mental representation is reversed can be found in the numerical domain. Bächtold, Baumüller, & Brugger (1998), provided an interesting demonstration of this phenomenon, asking participants to imagine numbers as presented on a ruler (small numbers on the left, large numbers on the right) or on a clock face (small numbers on the right, large numbers on the left). Authors found an opposite association, with faster left-effector responses for small numbers and faster right-effector responses for large numbers in the ruler condition, and faster left-effector responses for large numbers and faster right-effector responses for small numbers in the clock condition. Similarly, if the spatial association is influenced by the disposition of the notes on the specific instrument played, we can suppose that piano players will represent relatively high notes on the right side while flute players will represent them on the left side, and vice versa for relatively low notes.

To remove some possible spatial confounding properties of the stimuli, we decided to use only whole notes (i.e., notes without a stem). Therefore, the task in Experiment 2 consisted in judging whether the contour of the note was bold or normal, rather than to decide whether the stem was directed upwards or downwards, as in Experiment 1. Moreover, we used only the notes below the stave (G3, A4, C4, D4), because they can be presented in the same spatial position and can be recognised by the number of their lines and not by their position on the stave. This solution helped us to reduce the possibility for the orthogonal Simon effect to play an important role in explaining the results of the current experiment.

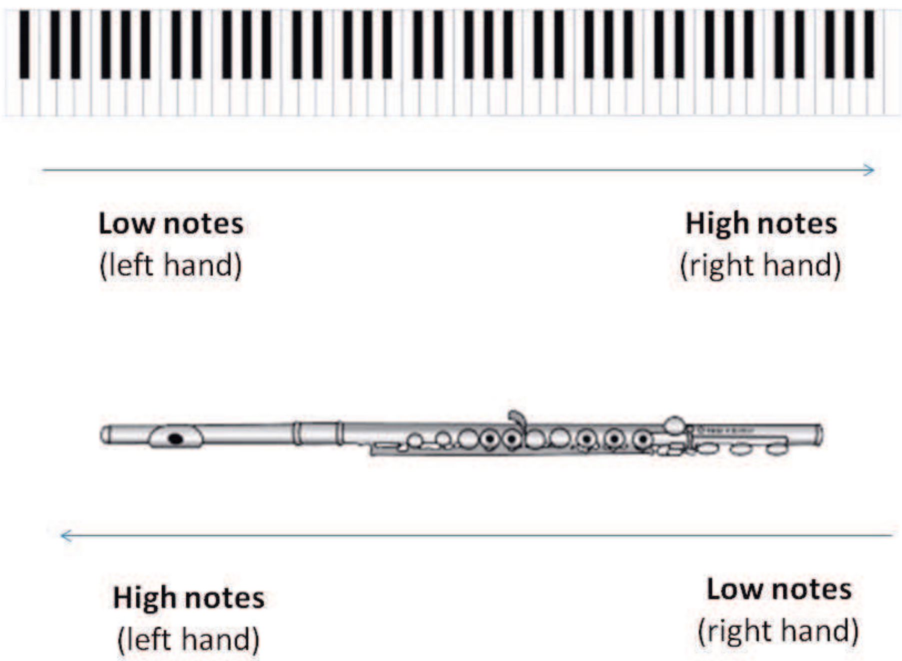

Figure 10. *The notes disposition on piano and flute keyboards.*

5.3.1 METHOD

5.3.1.1 Participants. Both participants (piano and flute players) were selected on the basis of their performance on a pre-test composed by questions concerning years of formal musical education, instrument played, and exams taken at a conservatory.

Piano players. Ten expert piano players participated in the experiment after giving their informed consent, seven females (mean age: 21.7) and three males (mean age: 22). They played piano as a main instrument and had taken courses and passed exams at a conservatory (mean frequency at a conservatory: 7.3 years).

Flute players. Fifteen flute players participated in the experiment after giving their informed consent, twelve females (mean age: 19.3) and three males (mean age: 19). They played piano as a main instrument and had taken courses and passed exams at a conservatory (mean frequency at a conservatory: 5.8 years).

5.3.1.2 Design. The experimental design was the same as that of Experiment 1.

5.3.1.3 Apparatus and stimuli. The apparatus was the same as in Experiment 1. Stimuli were musical notes presented as whole notes (colour: black), between G3 and D4, shown on the stave. Half the notes were bold and the other half were normal (Figure 11). B4 was excluded because it was the midpoint between G3 and D4. The notes were elliptical (1.98° in height by 2.37° in width). The stave measured 6.08° in height by 3.04° in width and it was centred within a white square (10° by 10°) that, in turn, was displayed in the centre of the screen against a black background.

5.3.1.4 Procedure. The procedure was the same as in Experiment 1, except for the use of a response box instead of a keyboard for recording RTs. Participants were required to decide whether the contour of the notes was bold or normal by pressing one of two response keys (i.e., one leftward and one rightward).

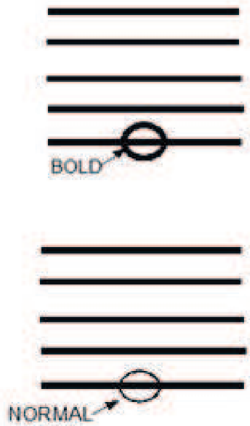

Figure 11. *Bold and normal stimuli in Experiment 2.*

5.3.2 RESULTS FOR EXPERT PIANO PLAYERS

Data analyses were the same as those in Experiment 1. The analysis of dRTs revealed that the regression slope was significantly different from zero, $t(9) = -1.878$, $p < .05$. This negative correlation, showed a relative left-effector advantage in processing notes lower than B4 and a relative right-effector advantage in processing notes higher than B4 (Figure 12).

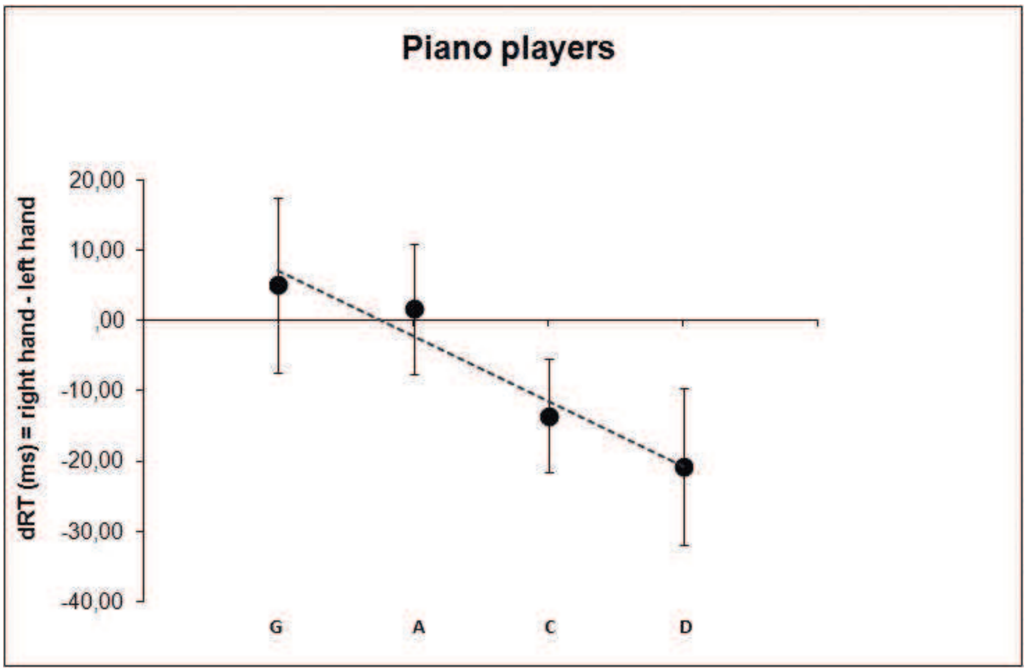

Figure 12. *Mean differences of the median RT right hand – RT left hand as a function of position of the notes on the stave in Experiment 2 for expert piano players. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses.*

5.3.3 RESULTS FOR EXPERT FLUTE PLAYERS

Data analyses were the same as in the previous experiment. The analysis of dRTs revealed that the regression slope was significantly different from zero, $t(14) = -3.036$, $p < .01$. As for the piano players group, also flute players showed a relative left-effector advantage in processing notes lower than B4 and a relative right-effector advantage in processing notes higher than B4 (Figure 13).

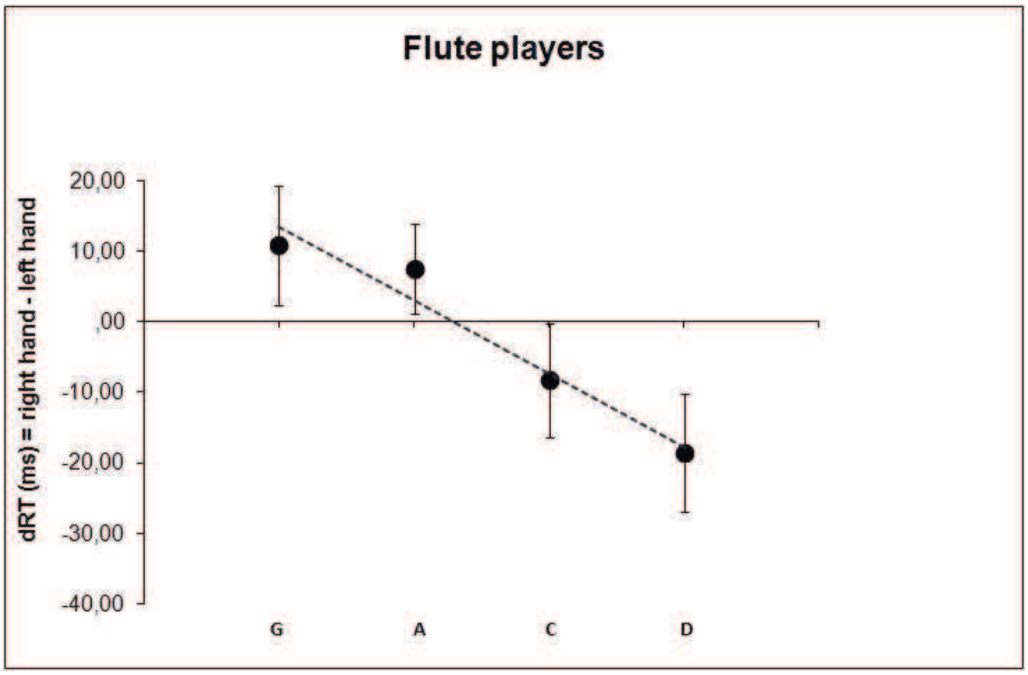

Figure 13. *Mean differences of the median RT right hand – RT left hand as a function of position of the notes on the stave in Experiment 2 for expert flute players. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses.*

5.3.4 DISCUSSION

The Results of Experiment 2 confirmed those of Experiment 1, showing an association between note height and the spatial properties of response, for participants with formal music education. Moreover, we replicated the results of Experiment 1 using lightly different stimuli (i.e., notes below the stave, instead of notes on the stave, and whole notes instead of notes with stem) and a different order-irrelevant task (i.e., decide if the contour of the notes is bold or normal, instead of decide if the stem of the notes is directed upwards or downwards). These expedients helped us remove some spatial feature of the stimuli (i.e., the position of the notes on the stave and the direction of stem of the notes) that could play a confounding role for proving a genuine SNARC-like effect for note height.

More importantly, Experiment 2 demonstrated that both piano and flute players show the same direction of the spatial association, with left-effector advantage for relatively lower pitched notes and right-effector advantage for relatively higher pitched notes. This evidence let us conclude that spatial representation for note height is not influenced by the specific musical instrument played. Therefore, this mental representation is universal amongst musicians.

5.4 GENERAL DISCUSSION

The aim of the present study was to investigate whether there is a relation between the written representation of musical notes and the side of response execution, and whether this association has the same properties in different kinds of musicians.

On the basis of our results, we suggest that only skilled musicians show a SNARC-like effect for written note height. In fact, expert musicians (i.e., mixed group in Experiment 1, piano and flute players in Experiment 2) show a left-effector advantage in processing relatively low notes and a right-effector advantage for relatively high notes. Otherwise, the amateur musicians group shows no such SNARC-like effect.

In both Experiment 1 (decide whether the stem of notes is oriented up or down) and Experiment 2 (decide whether the contour of notes is bold or normal) the participants' task was order-irrelevant. It means that the task does not require explicit access to a spatial representation of note height. The fact that such representation is nonetheless accessed shows that a spatial representation for musical notes is automatically activated when notes are processed by expert musicians. Moreover, this association seems not to be influenced by the spatial features of the stimuli, therefore it's a further demonstration that musical notation evokes a particular spatial mental representation of note pitch. Nonetheless, changes of the stimuli results (notes on the stave and notes with upward and downward stem in Experiment 1; notes below the stave and whole notes with bold or normal contour in Experiment 2) remain the same. The absence of spatial association in the amateur musicians group (Experiment 1) shows that results are due to a genuine SNARC-like effect for note height and not to an orthogonal Simon effect. Indeed, if the last one were the explanation for such an association, the same results would be found also for the amateur musicians group. Instead, the absence of a left-right advantage in processing note height shows that musicians without formal education have no clear access to note representation.

Experiment 1's data does not allow us to conclude whether the left-effector advantage in processing relatively low notes and the right-effector advantage in processing relatively high notes is due to an abstract representation for written musical notes, widespread among all musicians, or to the disposition of notes on the specific instrument's keyboard. Therefore, a group of expert piano players (low pitched notes are on the left side of the keyboard and high pitched notes are on the right; low pitched notes are played with the left hand while high pitched notes are played with the right hand) and a group of expert flute players (low pitched notes are displayed on the instrument's right side while high pitched notes are on the left side; low pitched notes are played with the right hand and high pitched notes are played with the left hand) were tested in Experiment 2. Both groups showed a left-effector advantage in processing relatively low notes and a right-effector advantage in processing relatively high notes, proving that the spatial association for written musical notes is not influenced by the specific disposition of the notes on the instrument played. Therefore, we can conclude that this note representation is universally widespread among musicians with formal education.

Furthermore, our results support Sloboda’s hypothesis (1976) that a mental representation of musical notation is present only in expert musicians. Our results are also in line with the findings of Gevers et al. (2003) that showed an association between non-numerical ordered sequences and spatial properties of the response. In fact, this association occurs not only for numbers, letters and months of the year, but even for musical notes. Indeed, numbers and notes are both symbolic languages that convey quantity information, about numerical quantities and pitch height respectively. We can speculate that, the absence of spatial association in participants without formal music education can be attributed to the lack of such "link" between the symbol (i.e., the written note in our case) and the information conveyed by itself (i.e., the pitch). Therefore, a note on the stave might be, for amateur musicians, like an "empty" sign instead of a symbol conveying pitch information. Hence, this could be the explanation for the lack of spatial association in the amateur musicians group of this study. From this point of view, the SNARC-like effect for written musical notes would be just an extent of the SMARC effect (Rusconi et al., 2006), conveyed by the symbolic language of music. Therefore, our findings complete the work of Rusconi et al. (2006) and Lidji et al. (2007) by showing that spatial representation exists not only for pitch height and, with less extent, melodic intervals but also for musical notation. Moreover, our study firstly investigated the relation between this representation and the instrument played by the participants.

Chapter 6

SPATIAL ASSOCIATION FOR NOTE VALUE

6.1 INTRODUCTION

With the term "music notation" we identify any system used for representing music through written symbols. In music notation, the note value indicates the relative duration of the represented note. For this purpose, note value is specified by the colour or the shape of the note head, by the presence or the absence of a stem, and by the presence or the absence of flags on the stem (Figure 14). Note value is also meant as a numerical value, representing the notes' duration as the number of beats inside a bar. In music, a bar (or measure) represents a unit of time defined by a given number of beats. Each measure satisfies a specified time signature. Therefore, if the measure is written in 4/4 time, a whole note will be enough to complete a bar. Alternatively, it could be completed by two half notes, or four quarter notes, and so on, with all the possible combinations.

The similarity between note value and numbers is quite obvious. Moreover, the whole metric system of music is controlled by mathematical rules and note value represents the music equivalent of numbers. In fact, note value is represented by symbolic signs conveying numerical information about the beat duration of a given note.

Note	Name	Beats
𝅝	Whole note	4 beats
𝅗𝅥	Half note	2 beats
♩	Quarter note	1 beat
♪	Eighth note	½ beat
𝅘𝅥𝅯	Sixteenth note	¼ beat

Figure 14. *Note value.*

A large number of studies investigated the relation between time and space, but no one specifically studied the spatial association for note value. Below are reviewed the main studies providing evidence about time and space or time - space - number magnitude interactions.

Evidence shows that common words and verbal expressions, that represent past and future events, can be associated with left and right space respectively (Santiago, Lupiáñez, Pérez, & Funes, 2007). In Santiago et al. (2007)'s study, participants were required to classify words as referring to the past or to the future by a left or right key-press. Words were visually presented and they consisted of tensed verbs (e.g., "(he) said", "(he) will say") or temporal adverbs (e.g., "tomorrow", "yesterday"). Stimuli appeared either to the left or right side of the screen. Results revealed that judgments were facilitated when word position and response mapping were congruent with the left-past and right-future coupling. A subsequent study by Santiago, Román, Ouellet, Rodríguez, Pérez-Azor (2010), showed that even meaningful event sequences (naturalistic scenes from commercial movies and sequences of photos) can be spatially represented. Participants were required to perform an order decision task showing both a left-right and distance effect. These studies provide important evidences for the left-to-right mental time line account, where past is represented on the left while future on the right.

Further studies demonstrated that writing direction can influence the representation of sequential events on the mental time line. Fuhrman and Boroditsky (2010) asked to English (who read from left to right) and Hebrew speakers (who read from right to left) to perform an order judgment about triplets of pictures representing objects, persons, animals and plants in three stages of time (early, middle or late) (Figure 15). Responses were provided by two adjacent keyboard keys. English speakers were faster to make "earlier" judgments responding with the left key than with the right key, while the opposite was true for "later" judgments. Otherwise, Hebrew speakers showed exactly the reverse pattern. Authors conclude that people do automatically access spatial information when making temporal order judgments and that this spatial layout depends on cultural-linguistic artifacts.

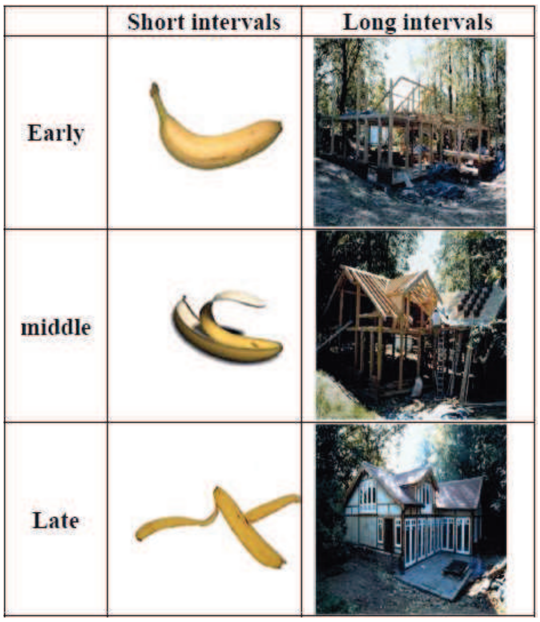

Figure 15. *Fuhrman and Boroditsky's (2010) stimuli used in temporal order judgment.*

Vallesi, Binns, and Shallice (2008), through a large number of experiments, demonstrated the existence of a spatial-temporal association of response codes effect for visually presented stimuli. Participants were required to judge the temporal duration of a centrally presented cross with different foreperiod durations (from 500 ms to 3500 ms). Results revealed that participants responded faster to short durations with the left response key and to long durations with the right key. The opposite was true when responses were given for short durations with the right hand and for long durations with the left hand. This data suggests that elapsing time could be represented through an internal spatial reference frame and that it may influence motor performance. Moreover, as stated by Vallesi et al. (2008), this stimulus-response compatibility effect fitted a rectangular function better than a linear one. However, it could be simply due to specific task instructions that required to dichotomously classify stimulus duration. This might have produced an order-relevant dichotomous spatial representation of elapsing time. Therefore, spatial-temporal representation of response codes should be further investigated using order-irrelevant tasks.

The left-to-right direction in the elapsing time representation was later confirmed by Vallesi, McIntosh, & Stuss (2011) with both behavioural and event-related potentials (ERPs) data. In particular, ERPs findings suggested an early pre-activation of left-hand responses and a later pre-activation of right-hand responses. This finding supports behavioural data providing differences in RTs between left and right responses for short and long duration stimuli.

Di Bono, Casarotti, Priftis, Gava, Umiltà, & Zorzi (2012) showed that task-irrelevant lateralized visuospatial primes affect duration judgments of auditory stimuli. In their study participants had to respond orally, by using two arbitrary nonwords (i.e., "Ti" and "To"), indicating whether a given probe tone was shorter or longer than a reference one. When short durations were paired to left-sided primes, rather than to right-sided primes, responses were faster. The opposite was true for long duration stimuli. This study provides further evidence for the left-right representation of short-long durations.

Conson, Cinque, Barbarulo, & Trojano (2008) claim that duration, order and space representations share common mechanisms, representing duration and order information through a spatially-defined magnitude system. In two experiments, authors showed that participants were more accurate, in duration judgment of pairs of tones, when the first tone was shorter and the second one longer. Moreover, short-first and long-second couplings were more accurate when responses were provided in the left-key and right-key conditions respectively.

Xuan, Zhang, He, & Chen (2007) investigated the interaction between different magnitudes and temporal duration. Participants had to judge the duration of four types of magnitude information (i.e., number of dots, size of open squares, luminance of solid square and numerical value of digits) manipulated in Stroop-like paradigms. Results showed that stimuli with larger magnitudes were judged to be temporally longer. These findings support the idea of generalized and abstract components in magnitude representation.

Further investigation aimed to extend Xuan et al. (2007)'s findings by investigating whether time and numbers are also connected at the response level stage. Therefore, Kiesel & Vierck (2009) asked participants to judge the parity status of single digits by pressing a response key for either a short or a long duration. Overall key-press durations were affected by number magnitude, moreover participants' responses were faster in congruent (small numbers-short key-presses, large numbers-long key-presses) rather than in incongruent conditions.

Bonato, Zorzi, & Umiltà (2012) provided an interesting and detailed review about time and space interactions. A large number of evidences shows that time interacts with spatial processing in a very similar way as numbers do. Bonato et al. (2012) discussed such empirical findings supporting the hypothesis that time is mentally represented in spatial format. Moreover, they claim that subjective time flow can be represented on a spatially oriented MTL (i.e., mental time line).

On the other side, Walsh (2003)'s idea more generally assumes that time, space and quantity share a common system for magnitude processing, located in the parietal cortex. His ATOM (i.e., A Theory of Magnitude Model) model is supported by several findings, from both behavioural and cognitive neuroscience studies, showing multiple and bidirectional interactions across three dimensions: time, space and number magnitude.

The aim of the present study was to investigate the spatial association for note value through both an order-relevant (Experiment 1) and order-irrelevant (Experiment 2) SNARC-like tasks. The first one allowed us to verify the existence of such an association, while the second one allowed us to explore its automaticity. We expected to find similar results as Dehaene, Dupoux, & Mehler (1990), firstly, and Dehaene, Bossini, & Giraux (1993), afterwards, found for numbers in both number comparison and parity judgment respectively.

6.2 EXPERIMENT 1

6.2.1 METHOD

6.2.1.1 Participants. Sixteen right-handed students of the State Conservatory of Music "Jacopo Tomadini" (Udine) took part to both Experiment 1 and 2. They were all flute players with a mean of 5.8 years of formal music education at the conservatory and a mean age of approximately 20 (age range: 17-24). Thirteen of the participants were female and three were male.

6.2.1.2 Apparatus and stimuli. The experiment was created and controlled by the E-Prime software, version 2.0. Stimuli were displayed on a 15.6 inch screen, with a 1280 x 800 pixels resolution. The PC was a Dell notebook with Intel Core i3 (RAM: 2 Gb). The Operating System was Windows 7 64-bit Edition. A five button Serial Response Box, connected to the pc by means of a serial port, was used for collecting responses.

Stimuli consisted of eight pictures representing four musical notes, with different duration values (i.e., whole note, half note, eighteenth note and sixteenth note), presented in the middle of the screen against a dim yellow background. Half of the stimuli were made by notes drawn with black contour and the other half with brown contour (Figure 16). Different note contour colours were needed for performing an order-irrelevant task. However, the same stimuli were presented in both experiments. The "quarter note" represented the middle reference point for the duration value judgment and was therefore excluded from the stimuli. No stave or other features appeared on the screen, just one isolated musical note at a time.

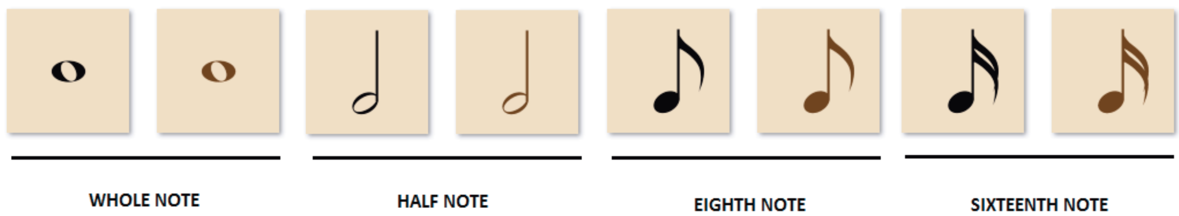

Figure 16. *The four note values drawn in black and brown contour used as stimuli.*

6.2.1.3 Procedure. The experiment took place in a quiet, dimly lit room, without environmental distractions. Participants were positioned in front of the PC. The midlines of the screen and the response box were aligned with the midline of the participant's body. The viewing distance was about 57 cm. Participants were instructed to move as little as possible and were asked to position their left index finger on the leftmost key and their right index finger on the rightmost key of the response box.

Each trial started with a fixation cross presented for 300 ms, followed by an inter-stimulus interval (ISI) of 130 ms. Then the target note appeared at fixation until a response occurred. Participants were asked to decide whether the presented note value was larger or smaller than the "quarter note", used as middle point reference, by pressing the leftmost and the rightmost keys. The experiment was divided into two sessions. In the first one, participants were asked to press the leftmost key with their left hand when the note's value on the screen was larger than a "quarter note" and the rightmost key with their right hand when the note's value was smaller than a "quarter note". In the second session, the assignment was reversed. The order of the two sessions was counterbalanced between participants. Each of the two sessions started with 8 training trials and then each note value was presented 20 times in random order. This resulted in a total of 80 trials in each session. The inter-trial interval (ITI) was 1500 ms.

Participants were allowed to take a short break between the two sessions if needed, otherwise they continued with the experiment. Both speed and accuracy were stressed in the instructions.

6.2.2 DATA ANALYSIS AND RESULTS

Experimental variables were manipulated within a repeated-measures design for regression analysis (Fias, Brysbaert, Geypens, & D'Ydewalle, 1996; Lorch & Myers, 1990). The predictor variable was the note value, whereas the criterion variable was the difference between reaction time (RT) of the right hand and RT of the left hand: dRT = RT(right hand) - RT(left hand). Positive dRTs indicate faster responses with the left button-press, whereas negative dRTs indicate faster responses with the right button-press. In the first step, for each participant the median RT of the correct responses was computed for each note value, separately for left- and right-hand responses. On the basis of these medians, dRT was computed by subtracting the median RT of left-hand responses from the median RT of right-hand responses. In the second step, a regression equation was computed for each participant with the note value as the predictor variable. In the third step, one-sample t-tests were performed to verify whether beta regression weights of the group deviated significantly from zero.

The analysis of dRT revealed that the regression slopes were significantly different from zero, $t(15) = -2.745$, $p < .05$ (Figure 17). The result shows a relative left key-press advantage in processing large note values (i.e., whole note and half note) and a relative right key-press advantage for small note values (i.e., eighth note value and sixteenth note value).

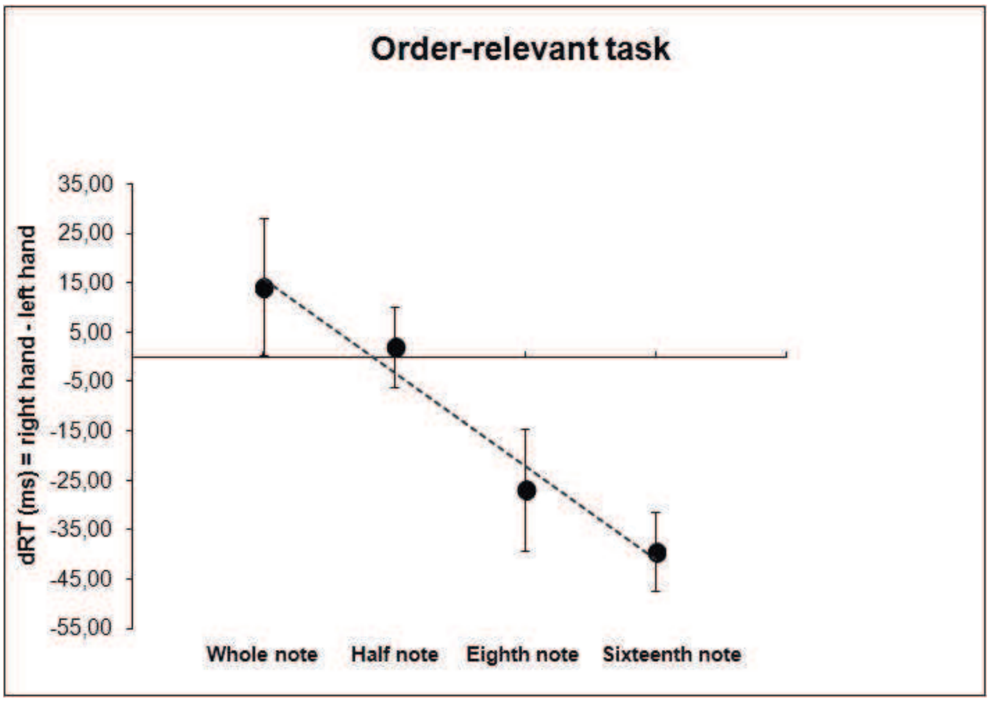

Figure 17. *Mean differences of the median RT right hand – RT left hand as a function of note value in Experiment 1. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses.*

6.3 EXPERIMENT 2

6.3.1 METHOD

Participants, apparatus and stimuli were the same as those of Experiment 1.

6.3.1.1 Procedure. The procedure was similar to those described in the previous experiment. The main difference was that participants were asked to decide whether the presented note was drawn with a black or a brown contour, by pressing the leftmost and the rightmost keys. Nothing about the note value was mentioned in the instructions or asked to the participants. The experiment was divided into two sessions. In the first one, participants were asked to press the leftmost key with their left hand when the note's contour was black and the rightmost key with their right hand when the note's contour was brown. In the second session, the assignment was reversed.

6.3.2 DATA ANALYSIS AND RESULTS

Data analyses were the same as in Experiment 1. The analysis of dRT revealed that the regression slopes were not significantly different from zero, $t(15) = -.301$, *ns.* (Figure 18). The result shows no left/right key-press advantage in processing different note values when an order-irrelevant task (i.e., contour colour judgment) was required.

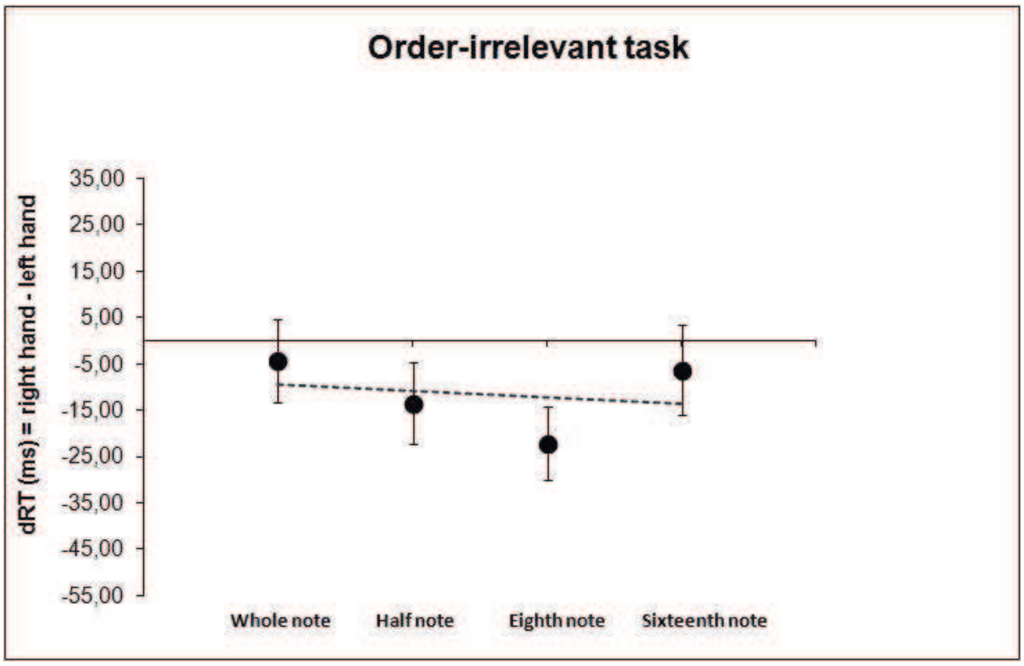

Figure 18. *Mean differences of the median RT right hand – RT left hand as a function of note value in Experiment 2. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses.*

6.4 DISCUSSION

The present study aimed to verify whether note value can produce similar spatial correspondence effects as numbers do in the SNARC effect (Dehaene et al., 1993).

Therefore, we asked musicians to perform both an order-relevant (i.e., note value comparison) and an order-irrelevant (i.e., note colour discrimination) task.

However, numbers are not the only elements to own a close relationship with space. A large number of studies investigated the relation between time and space, revealing several interactions between these two dimensions. Some evidence supports the hypothesis that time flow is represented with a spatial layout, so called, mental time line (Bonato et al., 2012).

All these evidences suggest the existence of a spatial association for note value, as it shares common features with both numbers and time. Note value represents a note's duration and therefore it seems strictly related with the domain of elapsing time and time flow. Otherwise, note duration is written with a symbolic language that conveys quantitative information, just as numbers. Even the names used for labelling note value (e.g., whole, half, quarter, eighteenth, sixteenth note, and so on) use mathematical language for representing note duration, more specifically, fraction names.

Our study partially confirmed this hypothesis, showing an association between note value and space but failing to demonstrate the automaticity of this association. In the order-relevant task, participants were required to judge whether the duration value of a note was larger or smaller than a quarter note. Results revealed a clear spatial association. Participants responded faster with the left key-press for whole and half notes, and faster with the right key-press for eighteenth and sixteenth notes. These results seem odd at first sight because we expected to find an association between small values and left responses and large values and right responses, like it is for numbers (Dehaene et al., 1993) and stimuli duration (Vallesi et al., 2008). Otherwise, our results fit better with findings provided for non-numerical ordered sequences. Gevers, Reynvoet, & Fias (2003) investigated the spatial organization for both months of the year and letters of the alphabet. Participants were asked to decide, by pressing a response key, whether a given month comes before or after June. Authors showed that months from the beginning of the year were responded to faster with the left hand than with the right hand, whereas the reverse was true for months towards the end of the year. Furthermore, in the experiment using letters of the alphabet, the task consisted in judging whether a given letter comes before or after “O”. Letters before

“O” were responded to faster with the left hand than with the right hand, whereas the reverse was obtained for letters after “O”. Similarly to months of the year and letters of the alphabet, note value is learned following a strict sequence direction, going from the largest note value to the smallest note value. This sequence is naturally used for listing notes values and it should be odd to find the reverse order. Therefore, it's plausible that the representation of note value is strictly related to this sequence direction and that note implied magnitude can't interfere with this over learned sequence. In the case of numbers, the order used for making a list follows an ascending direction, going from small numbers to large numbers. Differently, in the case of note value, the order used for making a list follows a descending direction starting from the longest note duration and going to the shortest one. These reversed order directions in representing magnitude of numbers and note values can account for the "odd" result provided in the order-relevant task. In conclusion, we can claim that the left-large duration value and the right-small duration value associations mirror the typical note value order direction and have no relations with the magnitude of the stimuli.

The absence of a spatial correspondence effect in the order-irrelevant task can be ascribed to two main explanations. The first one is that note values do not produce an automatic association with space and, therefore, the effect demonstrated in the order-relevant task is due to the task's request. The second explanation argues that the current order-irrelevant task (i.e., note colour discrimination) was not effective in demonstrating the spatial association for note value. In fact, the use of colour discrimination is quite controversial as different studies show ambiguous results with such features. The use of a colour discrimination task in Fumarola, Prpic, Da Pos, Mugia, Umiltà & Agostini (2014) clearly revealed an automatic association for luminance, whether the same feature was note effective in showing a SNARC effect for coloured digits (Fias, Lauwereyns, & Lammertyn, 2001). Fias et al., (2001) claim that the efficiency of order-irrelevant tasks depends on the degree of neural overlap of structures dedicated to process relevant and irrelevant information. Therefore, colour discrimination could be useful for investigating the luminance of the stimuli because of a high level of neural overlap between these two features, whereas it could be ineffective for investigating stimuli that require semantic processing, like digits and note value. At the current state of the research, we cannot surely claim whether the absence of a spatial association for note value in the colour discrimination is due to the lack of automaticity of such an association or to an ineffective order-irrelevant task. Therefore, further studies using different irrelevant features (e.g., superimposed oriented lines or triangles) are needed for solving such issues.

Chapter 7

SPATIAL ASSOCIATION FOR MUSIC TEMPO

7.1 INTRODUCTION

Tempo is an essential component of any music production and, together with melody and harmony, it contributes to define the essence of a music piece. In music terminology, tempo represents the pace and speed of a music composition and it affects the mood and the difficulty of a piece. The typical measure unit for tempo is the BPM (Beats per minute). Tempo can also be indicated with classical Italian tempo markings, going from "*Larghissimo*" (about 40 bpm or less) to *"Prestissimo"* (about 200 bpm or more).

The time component of music, as other musical parameters, is tightly coupled with mathematics and numbers. Indeed, the use of terms like "meter" and "measure" in music reflects the historical affinity between these disciplines. Moreover, in Old English the word "rhyme", derived to "rhythm", became associated and confused with the word "rim"[1] (i.e., number).

Many studies suggest that time and space are tightly coupled. It is possible that humans represent time as space and, in particular, time flow can be represented using a spatial layout or a mental time line. The great majority of studies in the time domain shows clear interactions with space and number magnitude. In fact the mental time line shares many features with the so-called mental number line (for a recent review see Bonato, Zorzi and Umiltà, 2012).

The first study providing strong evidences of space and numbers coupling was the work on the SNARC effect (i.e., Spatial Numerical Association of Response Codes), conducted by Dehaene, Bossini and Giraux (1993). Dehaene et al. found that, when participants'

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[1] *Chambers Twentieth Century Dictionary* (1977) Revised edition with new supplement. Edited by A. M. MacDonald. Edinburgh: W. and R. Chambers Ltd, p. 1100.

evaluation on the number parity status was required (i.e., participants had to decide whether a given number was odd or even), they were faster at judging the parity of large numbers (e.g., 9) when responses were executed with the right effector, whereas they were faster at judging the parity of smaller numbers (e.g., 1) when responses were executed with the left effector (i.e., left-hand key). The SNARC effect suggests that relatively small numbers are spatially represented in the left hemispace and relatively large numbers are spatially represented in the right hemispace. According to Dehaene et al., these findings suggested the existence of a left-to-right oriented mental number line (i.e., MNL).

An alternative explanation for the SNARC effect comes from Proctor and Cho (2006). The Polarity Correspondence Theory argues that, the association between left-hand advantage/small quantities and right-hand advantage/big quantities cannot be attributed to a certain representation with spatial characteristics. Otherwise, where binary responses are required, it can be attributed to a widespread tendency to polarize both the characteristics of stimuli and responses.

Some evidences for the existence of a SNARC-like effect in the music domain are provided by Rusconi, Kwan, Giordano, Umiltà and Butterworth (2006), who explored the spatial representation of pitch height using acoustic stimuli. The researchers observed a so-called SMARC effect (i.e., Spatial Musical Association of Response Codes) both when pitch height was task relevant (i.e., pitch comparison task) and when it was task irrelevant (i.e., Timbre judgment task). Moreover, both musically trained and naïve participants showed an association between “up” responses/high-pitched tones and “down” responses/low-pitched tones (i.e., vertical alignment) while only for musicians a consistent “right” responses/high-pitched tones and “left” responses/low-pitched tones association was observed (i.e., horizontal alignment). Naïve participants showed a trend toward the horizontal response association only in the task where pitch height processing was task relevant.

These findings were confirmed by Lidji, Kolinsky, Lochy and Morais (2007), in a series of experiments aimed to investigate the spatial representation of both isolated tones (i.e., the same of Rusconi et al., 2006) and two-note melodic intervals. Results show that vertical alignment is probably the most natural representation for the pitch height of isolated tones.

Indeed, this SNARC-like effect was observed for left-right association in naïve participants only in the pitch comparison task in which pitch processing was mandatory.

Although a wide amount of studies explored different temporal features, just a few investigations studied the relation between space and tempo in the auditory domain. The strongest evidence regarding the existence of an association between space and tempo was provided by Ishihara et al. 2008. Authors investigated the spatial representation of "time" using bimanual speeded responses to the onset timing (early or late) of a probe stimulus. The probe stimuli were preceded by periodic auditory clicks. In every trial participants listened to eight sequentially presented clicks, the first seven (i.e., reference stimuli) were separated by a fixed inter-onset interval (500ms) while the last one (i.e., probe stimulus) was experimentally manipulated to be earlier or later than the expected tempo (+/- 215ms). Participants had to indicate whether the probe click was "early" or "late" by pressing one of two response buttons. Results showed that responses to the left key were faster to early onset timing then to late onset timing, while responses to the right key were faster to late onsets than to early onsets. Authors named this effect STEARC (i.e., Spatial-TEmporal Association of Response Codes). Such a time-response congruity effect was observed only when response keys were aligned horizontally, while no effect was assessed with the vertical alignment of responses. Therefore, differently from pitch, horizontal response alignment seems to fit better with internal representation of tempo.

To explain the interaction between numbers, space and time, Walsh (2003) proposed an innovative account: the ATOM (i.e., A Theory Of Magnitude) model. According to the ATOM hypothesis, time and numbers are not actually represented in space but, more generally, they share with space a common system for magnitude processing. As stated by Walsh, this system is designed to process all the magnitude dimensions classifiable as “more than-less than”, “faster-slower”, “nearer-farther”, “bigger-smaller” (Bueti and Walsh, 2009). Concerning the authors this analogue system is placed in the parietal cortex.

The aim of the present study was to investigate whether an association exists between tempo and the side of response execution and whether this association has the properties of a left-to-right oriented mental line. We expected to find faster left-hand responses with slower beat sequences and faster right-hand responses with faster beat sequences. To test this hypothesis participants performed both an order-relevant task, the so called "Time comparison task" (i.e., Experiment 1), and an order-irrelevant task, the so called "Timbre judgment task" (i.e., Experiment 2). The first one allows us to investigate the spatial nature of internal representation, while the second one allows us to investigate the automaticity of the spatial codes activation.

7.2 EXPERIMENT 1

7.2.1 METHOD

7.2.1.1 Participants. Twenty-four volunteers participated in the experiment, 5 males and 19 females. The mean age was about 21 (range: 18-26). None of the participants attended music conservatory or received formal musical education.

7.2.1.2 Apparatus and stimuli. The experiment was created and controlled by the E-Prime 2.0 software version. The stimuli consisted of 10 digital wave audio tracks, half with the classic metronome timbre sound and half with a synthesized beep timbre sound. Different timbre beat sequences were needed because the order-irrelevant task (i.e., Experiment 2) required the participants to evaluate the timbre of the stimuli. Therefore, the same timbre sounds were used in both experiments. Both metronome and synthesized beep tracks had the same periodic rhythmical pattern and the same tempo. Probe beat sequences were 133 bpm, 150 bpm, 184 bpm and 201 bpm, while the middle range stimulus (i.e., 167 bpm) was the reference beat sequence. Audio stimuli were presented through a couple of AKG professional hi-fi stereo studio headphones. Before starting the experiments, subjects were asked to choose a comfortable level of volume. The PC was an Intel Core i3 (RAM, 2 GB), with OS Windows 7. Responses were collected using two keys of a five button Serial Response Box connected to the PC with a serial port.

7.2.1.3 Procedure. All the participants were tested individually in a quiet room under the supervision of the experimenter. Participants were positioned in front of the PC and both the midlines of the screen and of the response box were aligned with the midline of the participant's body. They were instructed to move as less as possible. Participants were then asked to position their left index finger on the 1st key of the response box (i.e., the leftmost key) and their right index finger on the 5th key of the response box (i.e., the rightmost key).

A fixation cross was presented for 300 ms at the beginning of each trial, followed by an inter-stimulus interval (ISI) of 130 ms. Then a four-beat reference sequence (i.e., 167 bpm) was presented, followed by a 800 ms fixation cross and 130 ms ISI. Thereafter a probe beat sequence was presented and participants were required to decide whether it was faster o slower than the reference stimulus. Participants were asked to respond as soon as they were ready. Therefore, they were not required to hear the whole probe sequence and they could interrupt it providing the response. Theoretically a two-beat probe sequence was quite enough for responding. Responses were given by pressing button 1 or 5 of the response box and, as soon as the response was provided, the probe stimuli stopped and a 1500 ms inter-trial interval (ITI) appeared before the whole sequence started again. Both speed and accuracy were stressed in the instructions.

The experiment was divided into two sessions. In the first one, participants were required to press the rightmost key (i.e., key number 5) with their right hand when the probe stimuli were faster than the reference beat sequence, and the leftmost key (i.e., key number 1) with their left hand when the probe stimuli were slower than the reference beat sequence. Participants received the opposite assignment in the second session. Each session started with 8 training trials and, then, each probe stimulus was presented 20 times in random order. Participants were allowed to take a short break between the two sessions if needed, otherwise they continued with the experiment. The sequence of presentation of each session was counterbalanced between participants.

7.2.2 DATA ANALYSIS AND RESULTS

Data analysis was carried out with the method of linear regression for repeated measures described by Fias et al. (1996) and Lorch and Myers (1990). The independent variable was the probe beat sequence tempo, while the dependent variable was the difference between reaction time (RT) of the right hand and RT of the left hand: dRT = RT(right hand) - RT(left hand). Positive dRTs indicate faster responses with the left effector, whereas negative dRTs indicate faster responses with the right effector. A regression equation was computed for each participant with tempo as the predictor variable and, finally, one-sample t-tests were performed to verify whether regression beta weights of the group deviated significantly from zero. Only correct responses were included in the analysis. Responses faster than 200ms or slower than 1500ms were considered as outliers, and therefore excluded from the analysis. Two participants were excluded because of a high number of errors (participant n° 11 = 23%, participant n° 21 = 7.5%) and a high number of outlier data (n° 11 = 100%, participant n° 21 = 47%). Therefore, only twenty-two participants were considered in the analysis. The analysis of dRT revealed that regression slopes were significantly different from zero, $t(21) = -2.294$, $p < .05$ (see Figure 19). The results show a relative left-effector advantage in processing slower beat sequences (i.e., 133 bpm and 150 bpm) and a relative right-effector advantage for faster beat sequences (i.e., 184 bpm and 201 bpm).

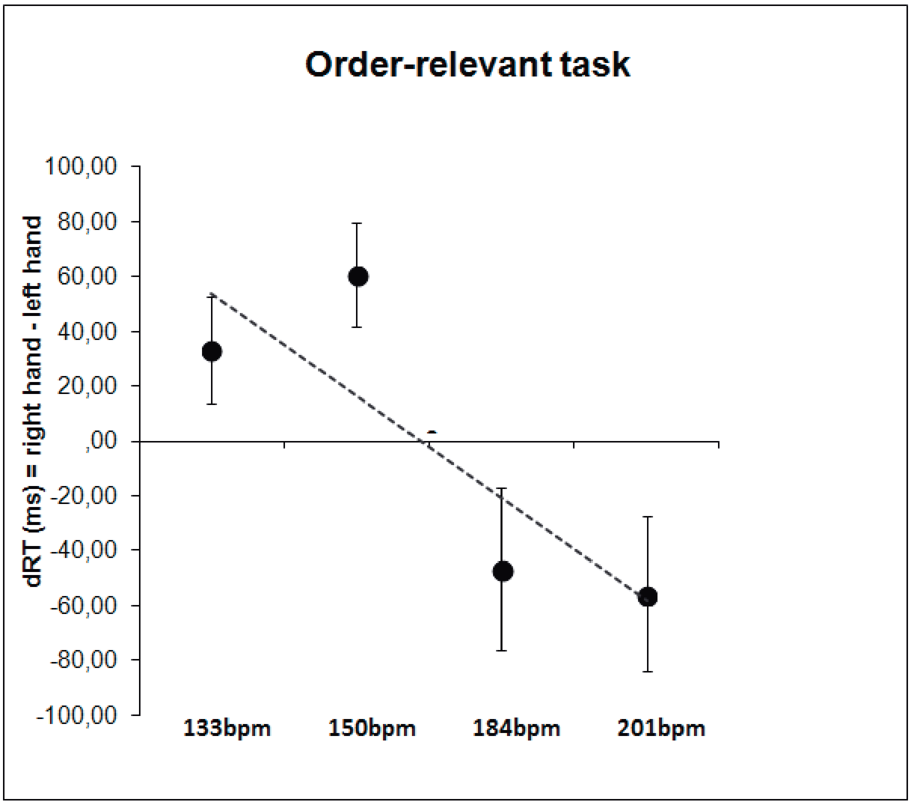

Figure 19. Mean differences of the median RT right hand - median RT left hand, for the order-relevant task. Positive values indicate faster left hand responses; negative values indicate faster right hand responses. Error bars indicate 95% confidence intervals around mean dRT.

7.3 EXPERIMENT 2

7.3.1 METHOD

Participants, apparatus and stimuli were the same as those in Experiment 1, except for the presence of a four-beat sequence with "neutral" timbre sound (i.e., a finger snap sound, clearly different in timbre from both probe beat sounds) before the probe sound sequence (metronome or synthesized beep sound).

7.3.1.1 Procedure. The procedure was similar to that described in the previous experiment. The main difference was that, after the first inter-stimulus interval (ISI), a sequence of four beats with a "neutral" timbre sound preceded the probe beat stimuli. The "neutral" timbre sequences had the same tempo as the probe sequences (i.e., 133 bpm, 150 bpm, 184 bpm and 201 bpm). There were no interruptions between the two sequences, only timbre changed at the fifth beat of the whole sequence. Therefore, the perceptual experience was that of a continuous sequence with the same inter-onset interval between all the eight beats. The first four beats had the "neutral" timbre sound, while the subsequent four beats could have either the metronome (half of the trials) or the synthesized beep (other half of the trials) sound. Subsequently, 1500 ms ITI was presented and the whole sequence started again. Participants were asked to decide whether the timbre sound of the probe sequence was a classic metronome sound or a synthesized beep sound, by pressing button 1 or 5 of the response box. By giving the response, participants could interrupt the probe beat sequence and it was not required for them to listen to the whole eight beat sequence. Theoretically, after the first probe beat (the fifth of the whole sequence) participants could decide whether the timbre was a metronome or a synthesized beep sound. The experiment was divided into two sessions. In the first one, participants were asked to press the rightmost key (i.e., button number 5) with their right hand when the timbre of the probe beat sequence was a metronome, and the leftmost key (i.e., button number 1) with their left hand when the timbre of the probe beat sequence was a synthesized beep sound. The assignment was reversed in the second session and the order of the two sessions was counterbalanced between participants.

7.3.2 DATA ANALYSIS AND RESULTS

Data analysis was the same as in Experiment 1. The analysis of dRT with tempo as the predictor variable revealed that the regression slopes were not significantly different from zero, $t(23) = -0.726$, *ns*. (Figure 20).

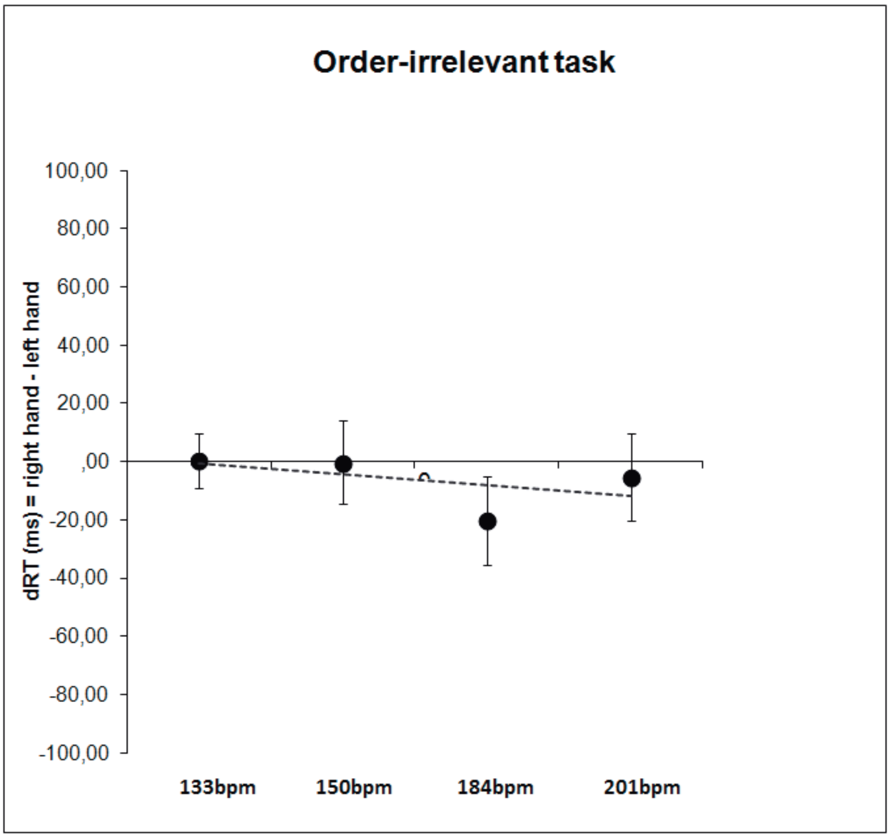

Figure 20. Mean differences of the median RT right hand - median RT left hand for the order-irrelevant task. Positive values indicate faster left hand responses; negative values indicate faster right hand responses. Error bars indicate 95% confidence intervals around mean dRT.

7.4 DISCUSSION

We investigated whether there is an association between music tempo and the side of response execution, and whether this association has the properties of a left-to-right oriented mental line. We expected to find faster left-hand responses with slower beat sequences and faster right-hand responses with faster beat sequences.

Our findings suggest the existence of a spatial association between music tempo and the space of response execution with the properties of a left-to-right oriented mental line. However this association was found only when participants performed an order-relevant task (i.e., Experiment 1) while no association was found in the order-irrelevant task (i.e., Experiment 2). Similar data were found for the same variables (i.e., musically untrained participants, horizontal alignment) in the pitch height domain by Rusconi et al. (2005) and Lidji et al. (2007). The absence of association between left-hand/slower beats and right-hand/faster beats in Experiment 2 can, therefore, be attributable to a double explanation.

Perhaps the horizontal alignment is not the “natural” representation for tempo, in the same way as pitch height of isolated tones are more “intuitively” represented on the vertical axis (Lidji et al., 2007). Indeed, the SNARC-like association for pitch of single tones was found for the horizontal alignment only in the order-relevant task, in which pitch processing was mandatory, while a vertical response association was found for both order-relevant and order-irrelevant tasks. If this assumption is correct, an “up” responses/fast tempo and “down” responses/slow tempo association should be found for both the Time comparison and Timbre judgment tasks. Additional evidence, used to predict the spatial representation of the stimuli in many SNARC and SNARC-like studies, is the existence of spatial features in common language expressions. For example, in the pitch domain, pitches are named as “high” or “low” suggesting a natural attitude for the vertical alignment. In a similar way, music tempo can be described using expressions as “high tempo/ high bpm rates” or “low tempo/low bpm rates” suggesting a vertical “predilection” for tempo as well. However, Ishihara et al.'s (2008) study showed an association between tempo (early or late probe stimuli) and the response location only for the horizontal alignment. This evidence suggests that pitch and tempo could be strictly different and, therefore, no specific forecast can be made about the vertical alignment. Further investigations involving vertical response alignment are needed.

A second explanation for the lack of the response side association in the order-irrelevant task could be the music expertise. As stated by Lidji et al. (2007), musicians are more prone to automatically process musical stimuli because of the high level of education and training. Indeed this could be the explanation for the right-effector/high pitched tones and left-effector/low pitched tones associations found with musically trained participants even in an order-irrelevant task. Similarly, the absence of formal musical training in participants engaged for the present work could be a plausible cause for the lack of response side association in the order-irrelevant task. Even in this case further evidence is needed. Therefore, the involvement of an expert musicians group seems fundamental for future researches.

Besides the mental line metaphor proposed by Dehaene et al. (1993), present results can also be explained in the light of the Polarity Correspondence Theory (Proctor & Cho, 2006). According to Proctor and Cho, stimuli are categorized as small (-) or large (+) before the activation of a response side. In our case, stimuli are different tempo sequences and they should be coded as slow (-) or fast (+) in comparison to the reference stimulus. Results in the first experiment could be due to this task request, which indicates a bipolar code that induces "positive" and "negative" responses. Otherwise, the absence of a significant effect in the second experiment can be due to the lack of an automatic association between space and music tempo. If so, spatial association for tempo differs radically from those of numbers (Dehaene et al., 1993), and it can be shown only when tempo processing is mandatory.

A rising issue, regarding the spatial association for music tempo, questions which variable actually produces this SNARC-like effect. There are two possible explanations: the beat frequency (i.e., the number of beats in a given lapse of time = bpm) or the temporal distance between the beats (i.e., the inter-onset interval IOI). As previously stated, Ishihara et al.'s (2008) revealed that short IOI produces a left-key advantage while long IOI produces a right-key advantage in processing a probe beat time position (early vs late). Therefore, if the spatial association for tempo is due to the beat's IOI, we should predict a left-key advantage for fast tempo (short IOI) and a right-key advantage for slow tempo (long IOI). Otherwise, our results mirror the opposite effect direction (i.e., left-key advantage for slow tempo and right-key advantage for fast tempo) suggesting an alternative explanation to the IOI. Indeed, the beat frequency account provides a more plausible explanation, as fast tempo is made by a larger number of beats for time unit while slow tempo is made by a smaller number of beats for time unit. Therefore, this explanation reflects the typical association between left side/small quantity and right side/large quantity shown with several types of magnitudes.

The existence of an association between music tempo and side of response execution leads us to hypothesize that tempo shares some features, not only with the pitch of isolated tones, but even with the wider domain of numbers and physical quantities. This idea agrees with the ATOM hypothesis proposed by Walsh (2003). According to this theory, time, space and numbers share a common system for magnitude processing, that is revealed by the spatial association of the response effectors.

Future directions of the research will be finalized to verify the existence of a spatial association of the response codes for tempo with the vertical alignment, for both order-relevant and order-irrelevant tasks. Moreover, the spatial-temporal association should be verified also for musically trained persons.

Chapter 8

LINEAR REPRESENTATION FOR PIANO TONES IN THE SMARC EFFECT: A PILOT STUDY

8.1 INTRODUCTION

In the SNARC effect (i.e., Spatial-Numerical Association of Response Codes), participants generally respond faster with the left-hand side to relatively small numbers and with the right-hand side for relatively large numbers when a parity judgment (odd/even) is required (Dehaene, Bosini & Giraux, 1993). Therefore, even when magnitude information is irrelevant for performing the task, an association between number magnitude and response position is observed. Dehaene et al. (1993) explained such evidence suggesting that, during parity judgments of Arabic digits, a representation of number magnitude is accessed in an automatic way. As stated by the authors, this representation may be connected to a spatially oriented mental number line (Restle, 1970), where small numbers are allocated in the left space and large numbers in the right space. Therefore, the SNARC effect would be the result of a direct correspondence between this mental representation and the execution of responses in the external space. Santens and Gevers (2008) called this theory the "direct mapping account".

These authors strongly opposed the direct mapping account, suggesting a different interpretation of Dehaene et al. (1993)'s results. They proposed two alternative accounts, called "intermediate coding" accounts, that don't imply a mental number line for explaining the SNARC effect. The first one (Gevers, Verguts, Reynvoet, Caessens & Fias, 2006) supposed a three layer model in which: the bottom layer represents number representation, the middle layer attributes numbers in conceptual categories depending on task requests (e.g., small/large, odd/even, etc.) and the upper level represents response alternatives. In a subsequent conceptual update (Notebaert, Gevers, Verguts & Fias, 2006), an abstract spatial code has been added to the model. Therefore, the categorical representations provided by the middle layer activate an abstract spatial code (e.g., left or right) before activating the response. Categorical representations, such as small/large or odd/even, are then associated with response alternatives. The second account, originally proposed by Proctor and Cho (2006), argue that stimuli and responses are both coded at an intermediate level as negative (-) or positive (+) polarities. This theory, also called "polarity correspondence principle", can be extended to a great variety of tasks and stimuli that can be coded on a bipolar dimension, not only to numbers. Both "intermediate coding accounts" state that numbers are coded as either small or large before the activation of a spatial response and, at a later stage, this magnitude representation is associated with the corresponding response alternative.

Santens and Gevers (2008) tried to show that the mental number line is not needed to explain the SNARC effect. Thus, they proposed a modified response mapping in a numerical comparison task. The experiment was designed to establish a spatial-numerical association to close and far responses, independently from left and right coordinates. Participants had to judge whether a given number (1, 4, 6, or 9) was smaller or larger than a reference standard (5). They had to move their right index finger to a close or far location on a computer keyboard. Half of the participants responded moving on the left side of the keyboard ("h" key for far and "j" key for close responses) while the other half responded moving on the right side ("l" key for far and "k" key for close responses). Every movement started from the middle key "j" and responses were thus labeled as being close or far from that key.

As stated by the authors, the direct mapping account predicts an advantage for close responses when responding to numbers close to the reference standard (5) on the mental number line (4 and 6), while an advantage is expected for far responses to numbers far from the standard on the mental number line (1 and 9). Therefore, given a reference middle point (5), a direct mapping is expected between the numerical distance on the mental number line (4 and 6 = close; 1 and 9 = far) and the physical distance of external responses.

On the other hand, the intermediate coding accounts predict that numbers are coded as smaller or larger than a reference standard (5) before the activation of a spatial response. Therefore, 1 and 4 (i.e., small numbers) should be associated with close responses, while 6 and 9 (i.e., large numbers) with far responses. An interaction is thus expected between the relative magnitude of a number (small/large) and the location of the response (close/far) without any connection to a spatial mental representation, as the mental number line.

Results provided by Santens and Gevers (2008) corroborate the latest prediction, showing faster close responses to small numbers (1 and 4) and faster far responses to large numbers (6 and 9). No effect of moving direction was provided, showing that participants were equally fast in responding to the left or to the right side of the middle key. This evidence argues in favor of the intermediate coding accounts, showing that the spatially oriented number line is not needed for explaining the SNARC effect.

Rusconi, Kwan, Giordano, Umiltà and Butterworth (2006) employed classical SNARC-like tasks and found that pitch height has a similar mental representation as numbers do. They called this effect SMARC (i.e., Spatial-Musical Association of Response Codes). In Experiment 1, musically untrained participants performed a pitch comparison task in which two pure tones had to be compared. Participants responded both with horizontal (left/right key-presses) and vertical (down/up key-presses) response alignments, showing a significant SNARC-like effect for both response mappings. There was a clear up/right and down/left response advantage for high- and low-frequency pitches respectively. In Experiment 2, non musicians had to classify relatively high and low pitched sounds as being produced by wind or percussion instruments (i.e., timbre judgment task). Results showed an advantage for up key-press responses with high pitched tones and for down key-press responses with low pitched tones, while there was no evidence for such association in the horizontal alignment. Note that, even for the vertical alignment, that association was shown only for large tone distances (4 tones distance from the implicit reference) while intermediate pitches did not seem reliably associated to the space of response execution. In Experiment 3, musicians performed the same timbre judgment task, showing both vertical and horizontal SNARC-like effects. Thus, the SMARC effect shows that, similarly to numbers, pitch height can also be mapped onto spatial coordinates. Moreover, it's true also when task instructions don't require the pitch to be processed directly (i.e., timbre judgment). Finally, Rusconi et al. (2006)'s work shows that music expertise is an important factor, as non musicians are less prone to process musical stimuli and, thus, to map them in a spatial code.

Lidji, Kolinsky, Lochy, and Morais (2007), confirmed Rusconi et al. (2006)'s findings using synthesized tones, with piano and violin timbre, instead of pure tones. Moreover, authors extended the study also to the contour of melodic intervals, showing, however, very limited evidence for a spatial association. The only reliable result of this association was found for the musicians group when performing a timbre judgment with horizontally aligned responses. Indeed, an association was assessed between descending/ascending contour intervals and left/right key-press responses respectively. Lidji et al. (2007) suggested that the "piano in the head" could be a culturally supplied spatial representation for musical stimuli, such as the "mental number line" is commonly used as a metaphor for number representation.

Taken together, these studies suggest that musical pitches and numbers share similar spatial representation and can produce comparable spatial-response correspondence effects, such as the SNARC and the SMARC effects.

The aim of the present study was to assess whether the spatial association for musical pitches fits the predictions resulting from the main opposite models proposed to account for the SNARC effect: the intermediate coding accounts (Gevers et al., 2006; Proctor & Cho, 2006) and the direct mapping account (Dehaene et al., 1993). In the first case, as stated by Santens and Gevers (2008) in a number comparison task (i.e., small numbers are associated to close responses and large numbers to far responses), relatively low pitched frequencies should be associated with close responses and high pitched frequencies with far responses. Otherwise, in the case of the direct mapping account, pitch height should follow a spatially oriented mental line representation, as proposed by Lidji et al. (2007) with the "piano in the head" metaphor. Therefore, pitches with frequencies close to the midpoint standard should be associated with close key-press responses, while pitches with frequencies far from the midpoint standard should be associated with far key-press responses.

For this purpose, we applied the modified SNARC paradigm used by Santens and Gevers (2008) to musical pitches. We attempted to establish a spatial association to close and far responses independently on left or right coordinates. Differently from Santens and Gevers (2008), we used an order-irrelevant task (i.e., timbre judgment) in which task requests are equal to those of the parity judgment, originally used by Dehaene et al. (1993) for investigating the SNARC effect. Indeed, order-irrelevant tasks are more informative about spontaneous and automatic associations, and avoid the risk to obtain results as an artifact induced by task instructions.

8.2 METHOD

8.2.1 Participants. Twenty-two musicians with formal musical education took part in the experiment. Half of them were male (mean age: 25, range: 19-32) and the other half were female (mean age:25, range: 19-36). They played different musical instrument (1 clarinet, 1 flute, 1 percussions, 4 guitars, 1 harpsichord, 1 oboe, 6 piano, 7 violin) with a mean of 14 years of practice among formal and informal studies. All of them have taken courses and passed exams at a conservatory.

8.2.2 Apparatus and stimuli. The experiment was created and controlled by the E-Prime software, version 2.0. Audio stimuli were presented through a couple of AKG professional hi-fi stereo studio headphones. The PC was a Dell notebook with Intel Core i3 (RAM: 2 Gb). The Operating System was Windows 7 64-bit Edition. A nine key usb DirectIN Button-Box was used for collecting responses.

Stimuli consisted of four pitched tones with different height values (E2, C#4, D#5, and C7), while the middle pitch value (G#4) was never presented. Stimuli were created to have the perfect fifth interval (7 semitones) as a distance unit, thus, three perfect fifth intervals (21 semitones) separate E2 from C#4 and D#5 from C7, while two perfect fifth intervals (14 semitones) separate C#4 from D#5. The distance ratio between stimuli mirrors the one used by Santens and Gevers (2008) in their study (i.e., from 1 to 4 = 3 units, from 4 to 6 = 2 units, and from 6 to 9 = 3 units). Therefore, the distance between close numbers/pitches and the midpoint (5 for numbers and G#4 for pitches) was 1 unit, while the distance between far numbers/pitches and the midpoint was 4 units (Figure 1). Half of the pitched tones were presented with a synthesized violin timbre sound and the other half with a synthesized grand piano timbre sound.

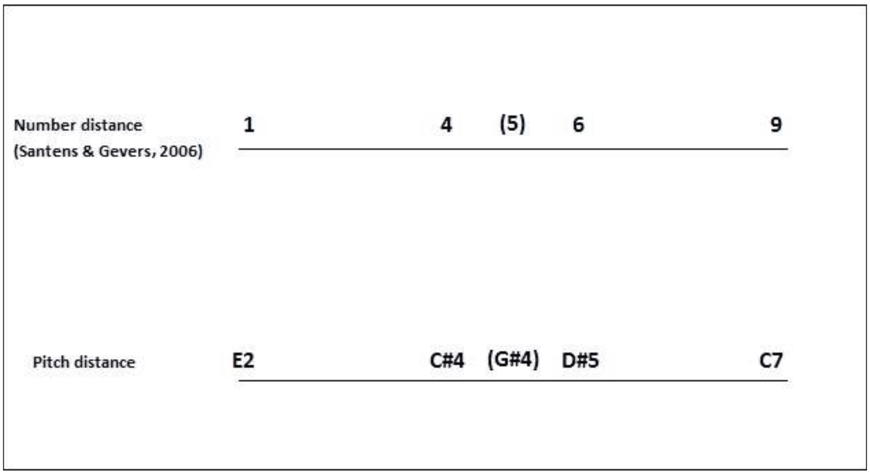

Figure 21. *Linearly represented stimuli's distance for numbers (Santens & Gevers, 2008) and pitches.*

8.2.3 Procedure. The experiment took place in a quiet, dimly lit room, without environmental distractions. Participants were positioned in front of the PC. The midlines of the screen and the response box were aligned with the midline of the participant's body.

Each trial started with a 1000ms fixation cross, then a hash mark (#) appeared at fixation until participants pressed the middle key (key number 5) with their right index finger. As soon as this key was pressed, a target pitched tone was heard through the headphones and participants had to decide whether the colour of the pitch was violin or piano timbre sound. In one block, participants had to move their finger and press the close response key as the timbre was a violin sound, whether they had to move and press the far key as the timbre was a piano sound. In the other block, the timbre/response-key mapping was the opposite one (i.e., violin timbre/far key-press; piano timbre/close key-press). The response mapping was manipulated within subjects and the order of the two blocks was counterbalanced over participants. The moving direction was counterbalanced among subjects: half of the participants always moved their finger to the left (close key number 4; far key number 2) and the other half to the right (close key number 6; far key number 8). All the participants used only the right index finger for providing the responses and the movements were always executed starting from the middle key to the target keys. After the response, a 500ms inter-trial interval (ITI) appeared before the whole sequence started again. There were two blocks of 64 trials, thus, each target pitch was repeated 16 times per block (8 with violin and 8 with piano timbre sound). The order of presentation of the target stimuli was randomized in every block. Each of the two sessions started with 8 training trials with accuracy feedback, to adapt participants to the correct response mapping. Participants were allowed to take a short break between the two sessions if needed, otherwise they continued with the experiment. Response keys were labeled in the instructions as being close or far from the middle key. No reference to small or large movements, left or right directions, and response key number was made. Both speed and accuracy of the target response were stressed in the instructions, while no specific instructions were given for the middle key pressing and releasing speed.

8.3 DATA ANALYSIS AND RESULTS

Participants made just a few errors (1.9% of all trials) so it was not possible to conduct analysis on accuracy rates.

Correct trials were included in the RT analysis. Moreover, RT faster than 200ms (0%) and slower than 1000ms (2.6%) were excluded from the analysis. A mixed ANOVA was run with a 2 (movement direction: left/right) by 2 (instrument timbre: piano/violin) by 2 (responses location: close/far) by 4 (pitch height: E2, C#4, D#5, C7) design. Movement direction was treated as a between-subjects variable, while instrument timbre, response location and pitch height were treated as within-subjects variables. There was a main effect of the instrument timbre $F(1, 20) = 8.37$, $p < .01$, meaning that piano and violin timbre sounds were not equally easy to judge. A main effect of the response location was observed $F(1, 20) = 103.26$, $p < .001$, showing that responses to a physically close key were executed faster than responses to a far key. There was also a main effect of pitch height $F(3, 60) = 15.86$, $p < .001$, but no interactions between pitch and movement direction $F(3, 60) = .59$, $p = .622$, showing that there was no influence of pitch height to the movement direction (left/right). More importantly, the interaction between pitch height and response location reached significance $F(3, 60) = 2.94$, $p < .05$.

The main effect of instrument timbres suggested to provide separate analyses for violin and piano stimuli. Therefore, a mixed ANOVA was run with a 2 (movement direction: left/right) by 2 (responses location: close/far) by 4 (pitch height: E2, C#4, D#5, C7) design for both violin and piano timbre sounds. Only piano showed a significant interaction between pitch height and response location $F(3, 63) = 3.42$, $p < .05$ (Figure 2), while there was no interaction for violin stimuli $F(3, 63) = 0.75$, $p = .52$.

Results showed that participants were generally faster to respond with a physically close response key-press for pitches close to the midpoint (C#4 and D#5) than to pitches far from the midpoint (E2 and C7). On the other hand, no such differences appeared with a physically far response key-press.

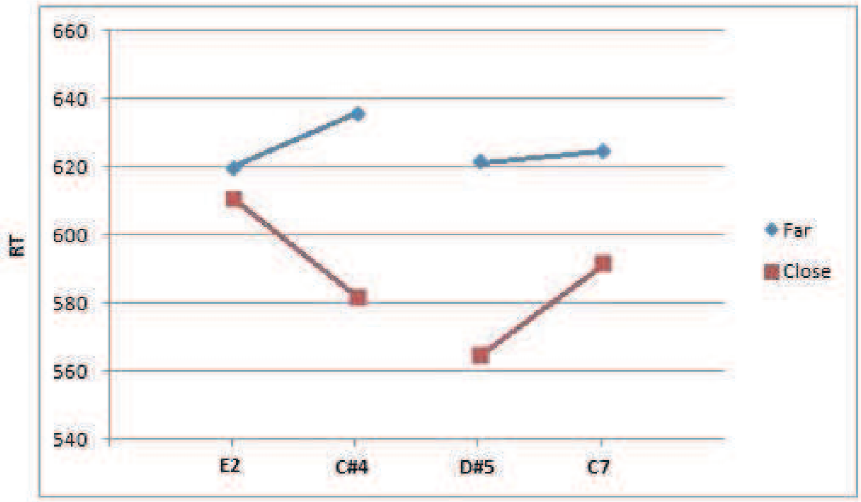

Figure 22. *Timbre judgment for piano timbre sound*

8.4 DISCUSSION

The present study was designed with the aim to verify whether the spatial association for pitch height, also called SMARC effect (Rusconi et al., 2006), is better explained by the intermediate coding accounts (Gevers et al., 2006; Proctor & Cho, 2006) or the direct mapping account (Dehaene et al., 1993).

In the numerical domain, Santens and Gevers (2008) published an interesting work that breaks with the idea that a mental number line is needed as an explanation for the SNARC effect. Using a number magnitude comparison task, these authors showed evidence supporting the intermediate coding accounts, while discrediting the direct mapping. Indeed, numbers close to the comparison standard (4 and 6) and far from the standard (1 and 9) were not associated with a physically close and far response key-press respectively, as the direct mapping account predicts. Otherwise, small number magnitudes (1 and 4) and large number magnitudes (6 and 9) were associated with a close and far response key-press respectively. This evidence shows that numerical stimuli are coded at an intermediate coding level as large (+ polarity) or small (- polarity) and subsequently associated with responses in the external space.

In the present study we introduced the same coding (close and far responses) proposed by Santens and Gevers (2008) in an order-irrelevant task (i.e., timbre judgment) using musical tones with different pitch frequencies. The results showed a different pattern in the pitch height domain compared to the number domain, suggesting pitches close to the midpoint (C#4 and D#5) to be associated with physically close response key-presses and pitches far from the midpoint (E2 and C7) to be associated with physically far response key-presses. Analyzing piano and violin timbres separately, this tendency was clearly revealed in the piano condition while no interactions between pitch height and response location existed for the violin condition.

Comparing our results (Figure 2a) with the results obtained by Santens and Gevers (2008) (Figure 2b) and a theoretical model of the direct mapping account prediction (created using the same data provided by Santens and Gevers, 2008) (Figure 2c), it looks quite clear that our data support the direct mapping account and reject the intermediate account hypothesis in the pitch domain. Surprisingly only piano stimuli showed an interaction between pitches and response location, while violin stimuli were not associated to close and far responses.

One possible explanation for such results is that the response mapping and the physical structure of the response box activated a piano keyboard representation. Indeed, the horizontally displayed response keys used in the experiment were compatible with a piano keyboard structure and this could be a possible explanation for different results found for piano and violin timbre sounds. Maybe different timbre sounds (piano and violin) activate specific representations of pitches according to the instrument structure. However, showing an interaction between pitch and response location only when such pitch representation overlaps with the external response mapping. In this case, violin timbre representation of pitches did not find any overlap possibilities with the key-press disposition used in our experiment, while piano certainly did. Moreover, piano knowledge is largely widespread among musicians with formal education, as all conservatory courses required basic piano exams. Thus, the "piano in the head" metaphor proposed by Lidji et al. (2007) is a proper explanation for current results and provides support for a linear representation of piano tones.

Finally, our results are in line with the predictions derived from the direct mapping account. However, only close responses supported this hypothesis, while far responses showed no interactions with pitch height. Note that, the task difference between our experiment (timbre judgment) and Santens and Gevers' (2008) one (number comparison) does not allow us to make strong claims about the difference in obtained results. Performing a second experiment, as an order-relevant task (pitch comparison) will certainly make it easier to compare evidence provided for number magnitude and pitch height. Indeed, in the order-relevant task the use of an explicit midpoint reference standard will probably enhance the effect found in the present experiment, where no explicit reference was provided during the whole task. The use of an order-irrelevant task (e.g., timbre judgment), is although important as the associations are not obtained as an artifact of task instructions, conversely they are due to spontaneous and automatic mechanisms. In our case, these associations suggest a linear representation for piano pitches in line with the direct mapping account.

Furthermore, to solve the issue concerning the different results obtained with different timbre sounds, the use of pure tones in addiction to piano and violin sounds should be also investigated. This will allow us to make more general conclusions about pitch representation.

In conclusion, more investigations are needed to clarify the role of both intermediate coding and direct mapping theories, in order to account for the stimulus-response correspondence effects in both numbers and pitches. A single experiment cannot be considered at all a sufficient evidence to support or reject a theory. Therefore, more studies should be done in order to deepen theoretical implications of the investigated phenomena. In the widespread literature about the SNARC effect, the work of Santens and Gevers (2008) is still a rare example of such tendency.

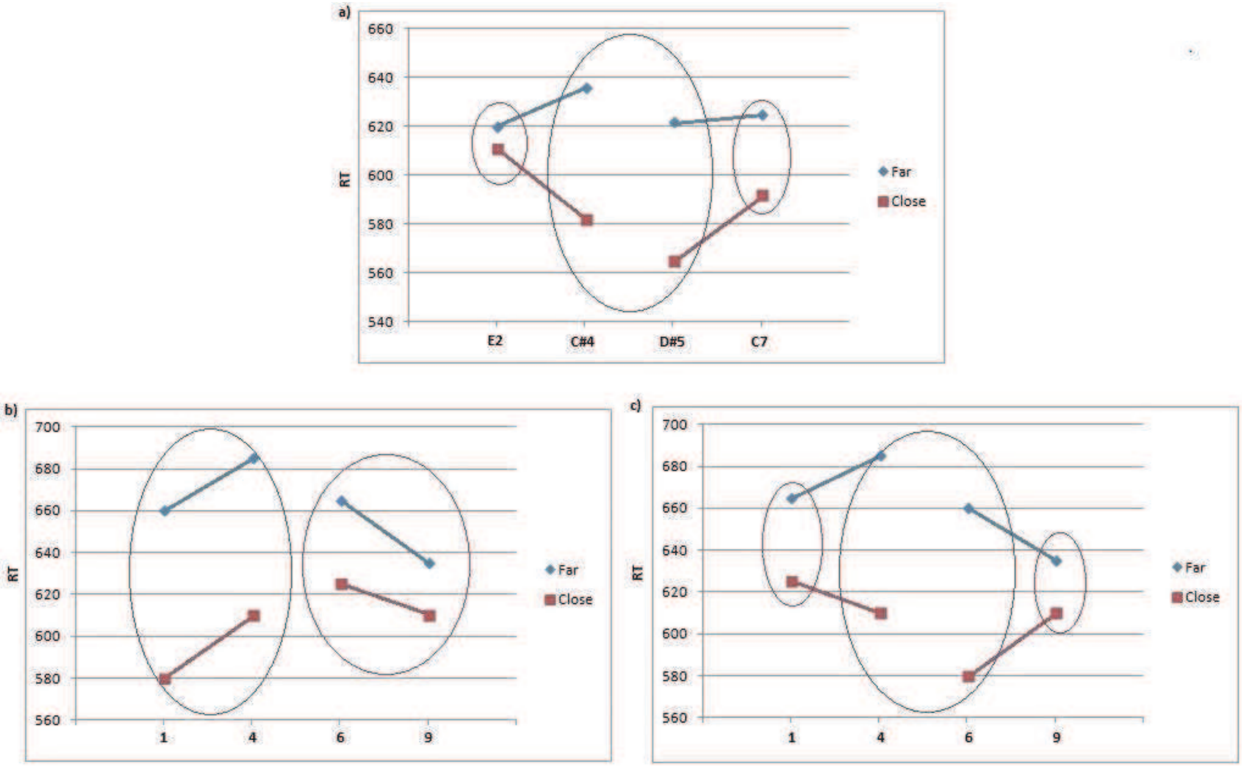

Figure 23. *a) Timbre judgment for piano timbre sound; b) Number comparison, Santens & Gevers (2008); c) The direct mapping account (Dehaene et al., 1993) prediction for number comparison, computed on the basis of Santens & Gevers (2008)'s data.*

Chapter 9

GENERAL DISCUSSION

This thesis shows that, not only numbers (Dehaene et al., 1993) and pitch (Rusconi et al., 2006; Lidji et al., 2007) but also different music parameters are strictly related with space. More precisely, several parameters of music inherently reflect quantity and order information, thus an association was repeatedly found between musical stimuli and the space of response execution.

Two visual (i.e., note height on the stave and note value/duration) and two auditory (i.e., music tempo and pitch height) sets of musical stimuli were investigated in chapters five, six, seven and eight, respectively. One of the visual and one of the audio stimuli concern music tones (i.e., note height on the stave and pitch height), while the other ones concern temporal aspects (i.e., music tempo and note value/duration). Therefore, a complete overview of music parameters and their relation with space was proposed. In general, each of the stimulus sets investigated in this thesis revealed to be in some way linked with space. Specific considerations for each of the experimental studies are provided below.

In the fifth chapter the spatial association between note height on the stave and the space of response execution was assessed. Only musicians with formal education showed a left/right key-press association for relatively low/high notes, while amateur musicians showed no evident association in the order-irrelevant task. Importantly, the absence of the spatial association in amateur musicians revealed that the effect was not due to an orthogonal Simon effect (Bauer & Miller, 1982), instead it was due to a genuine SNARC-like effect for note height. This evidence extended previous findings on the spatial association for auditory pitch height (Rusconi et al., 2006; Lidji et al., 2007) to its written representation. Moreover, a further experiment examined the direction of this association in a group of piano and flute players, as the note disposition on these instruments has a reversed direction (left/right for relatively low/high notes in the piano; right/left for relatively low/high notes in the flute). Both piano and flute players showed the same association direction (i.e., faster left/right key-presses for relatively low/high notes), revealing that the association was not influenced by the disposition of the notes on the specific instrument played. Concluding, the effect seems to reflect a universal association, between note height and the space of response execution, for musicians with formal education.

In the sixth chapter, a spatial association for visually presented note value/duration was investigated in professional musicians. The order-relevant task (note value comparison) showed a clear association between note value and the space of response execution, while such association was not assessed in the order-irrelevant task (note colour discrimination). However, the absence of the association in the order-irrelevant task can be due to the inappropriateness of task requests, as colour discrimination showed to be ineffective for assessing a spatial association for numbers (Fias et al, 2001). Thus, further investigations are needed to assess the automaticity of spatial association for note value/duration. Surprisingly, the association in the order-relevant task revealed a reversed direction from the expected one. Participants generally responded faster to relatively long duration notes (i.e., whole and half notes) with the left key-press and to relatively short duration notes (i.e., eighth and sixteenth notes) with the right key-press, while the opposite association was expected. This association seems to reflect the over-learned sequence used for representing note value, namely a descending direction from the longest note duration (e.g., whole note) to the shortest one (e.g., sixteenth). The magnitude information (i.e., note duration) conveyed by the note value thus, does not seem to influence the direction of the association. It has to be noted that, note value is a rare case in which the usual sequence of order representation places large magnitudes on the left and small magnitudes on the right. This feature gives to note value a great importance to discriminate between the magnitude and the sequence order as the cause of the spatial association. Current evidence seems to highlight the importance of order and reduce the role of magnitude.

In the seventh chapter, the existence of a spatial association for music tempo was assessed in participants without formal musical education. Participants showed a clear left/right key-press advantage for relatively slow/fast tempo, when asked to judge a series of auditory beat sequences to be faster or slower than a middle reference standard. There was no sign of spatial association in the order-irrelevant (timbre judgment) task, showing a lack of automaticity in the association for non-musicians. More evidence is needed to verify the existence of a SNARC-like effect in the order-irrelevant task for musicians. However, non-musicians showed to couple low/high beat frequency rates with the left/right space when tempo was the order-relevant variable, even if lacking musical expertise. This demonstrates the familiarity of the "tempo" experience in everyday life, expanding its role beyond the music domain.

In chapter eight, a spatial association for pitch height was assessed in an alternative version of the SMARC effect (Rusconi et al., 2006). When participants were involved in an order-irrelevant (timbre judgment) task, responses were coded as "close" or "far" to a referent key instead of the traditional mapping to left-right responses. This expedient allows us to verify predictions based on the direct mapping account (Dehaene et al., 1993) and the intermediate coding accounts (Gevers, Verguts, Reynvoet, Caessens & Fias, 2006; Proctor & Cho, 2006). Contrary to Santens and Gevers' (2008) study, which found numbers to support the intermediate coding accounts, pitch height seems to be represented linearly, according to the direct mapping account (Dehaene et al., 1993). The association between close/far responses and relatively close/far pitches were found only for piano timbre, suggesting a linear representation of piano tones in line with the piano keyboard. This finding supports the "piano in the head" metaphor proposed by Lidji et al. (2007), as the piano represents a standard model for western music. Differently from Santens and Gevers (2008), a spatial association to close and far responses was assessed in an order-irrelevant task (timbre judgment), proving the existence of an automatic association also for this unconventional coding. However, to deeply investigate the phenomenon, an order-relevant task (pitch comparison) will allow to compare easily the results with the one found by Santens and Gevers (2008). Moreover, stated the importance of the timbre in the present experiment, the use of pure tones should also be informative for future studies.

Overall, evidence seems to support the ATOM model (Walsh, 2003), which claims the existence of a common system for processing space, time and numbers. Indeed, several music parameters were shown to be strictly related with space, proving that most of the parameters of music convey magnitude information and are prone to interfere with space as do numbers (Dehaene et al., 1993). Looking back at the predictions proposed by Walsh (2003) in the ATOM model, the SNARC effect should prove to be a SQUARC (i.e., spatial quantity association of response codes) effect, namely to be widespread to various types of magnitudes. Currently provided evidence supports this idea, showing that the spatial association, originally found for numbers by Dehaene and colleagues (1993), can be verified also for other kinds of magnitudes, such as most of the parameters of music.

Concluding, this thesis provides a complete review of the spatial association for musical stimuli, extending previous evidence found for pitch height (Rusconi et al., 2006; Lidji et al., 2007). Lidji et al. (2007) argued against the name SMARC (i.e., Spatial-Musical Association of Response Codes), proposed by Rusconi et al. (2006) to account for the spatial association found with musical pitches. They claimed that pitch is just one isolated component of music and cannot be labelled as a spatial-musical association, as proposed by Rusconi et al. (2006), but may be more properly called SPARC (Spatial-Pitch Association of Response Codes) effect. Conversely, they proposed to use the name SMARC for the spatial association effect found for melodic intervals, as more representative of music than isolated pitches. Nevertheless, Rusconi et al. (2006) used the name SMARC for labelling the spatial association effect found to be stronger in the musicians group and did not refer specifically to the pitch. However, the use of the name SMARC remains certainly confused in literature. Therefore, I propose SMARC to be a general category for each of the SNARC-like effects revealed within musical stimuli sets. Indeed, different music parameters showed to be associated with space (i.e., pitch height, note height, note value/duration, music tempo) and this was proved to happen not only for musicians (e.g., music tempo).

LIST OF FIGURES

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"Trough and through the world is infested with quantity: To talk sense is to talk quantities. ..... You cannot evade quantity. You may fly to poetry and music, and quantity and number will face you in your rhythms and your octaves."

- Alfred North Whitehead-

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