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MOTOR IMAGERY AND MUSIC: THE INFLUENCE OF MUSIC ON MENTAL ROTATION TASKS IN THE LIGHT OF THE EMBODIED COGNITION THEORY

Fernando Dantas Castellar

Dissertação de Mestrado

MESTRADO EM CIÊNCIA COGNITIVA

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Dissertação de mestrado orientada pelo Prof. Dr. David Yates e pelo Prof. Dr. Pedro Alexandre Duarte Mendes como requerimento parcial para a obtenção do grau de mestre em Ciência Cognitiva

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To my parents

and to my sister Gabriela

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Abstract

The Embodied Cognition Theory (ECT) has become a hot topic in Cognitive Science, providing the investigation of cognitive phenomena with food for thought through a wide range of empirical findings. Two core claims from ECT were investigated in the present study: **1)** the non-neural parts of an organism's body play a constraining role in cognition; and **2)** all concepts (strong embodiment) or some concepts (weak embodiment) are grounded in modality-specific areas of the brain. In line with **2)**, studies on mental imagery of bodily-related movements (henceforth: motor imagery) suggest that we use motor concepts grounded in modality-specific areas of the brain (the motor cortices) when we carry out motor simulations of our own body (Jeannerod, 2006), including in cognitive tasks such as MR of bodily-related pictures (Parsons et al., 1995). Also, studies in music perception have correlated the cortical activation of motor areas of the brain with rhythmic perception, varying in degree of activation according to the rhythmic complexity of a stimulus (Grahn & Brett, 2007). Finally, these assumptions predict the Mozart Effect, which consists of subjects' temporary enhancement in performance at spatial-temporal reasoning tasks, including MR tasks (Rauscher, Shaw & Ky, 1993).

Based on these assumptions, it was investigated whether subjects' (N= 36) performance at a MR of bodily-related pictures would differ after exposure to musical pieces with different levels of rhythmic complexity and a control condition (silence). Results show that, although subjects' performance was affected by the biomechanical constraints of their own bodies, suggesting that the body biomechanics play a constraining role in cognition, the Mozart Effect was *not* observed, suggesting that either 1) weak conceptual embodiment may not be true for motor imagery, and motor concepts are not grounded in modality-specific brain areas, 2) the musical samples used in the present study were not adequate to elicit sufficient cortical activation that would eventually result in performance enhancement, or 3) the Mozart Effect is due to reasons other than cortical activation of modality-specific brain areas, such as increase in arousal/mood levels or an artefact of subjects' preference for a stimulus (Chabris, 1999).

It is suggested that future research employs brain-mapping techniques, such as Positron Emission Tomography (PET Scan), Functional Magnetic Resonance Imaging (fMRI), or Electroencephalogram (EEG) to strengthen one or more hypotheses that account for the failure in observing the Mozart Effect in this study by identifying which brain areas were involved during the listening task and/or the MR of bodily-related pictures.

Keywords: Embodied Cognition Theory, conceptual embodiment, motor imagery, rhythmic perception, Mozart Effect

Resumo

A Teoria da Cognição Corporificada (ECT) tem se tornado um tópico amplamente discutido nas Ciências Cognitivas, uma vez que uma ampla gama de descobertas empíricas tem provocado reflexões a respeito da cognição. Duas fortes suposições da ECT foram investigadas no presente estudo: **1)** as partes não neurais do corpo de um organismo possuem um forte papel de limitação sobre a sua cognição; e **2)** todos os conceitos (corporificação forte) ou alguns conceitos (corporificação fraca) estão ancorados em regiões cerebrais de modalidade específica. Alinhado à **2)**, estudos em imaginação motora sugerem que nós utilizamos conceitos motores ancorados em regiões cerebrais de modalidade específica (córtices motores), para realizarmos a simulação de atos motores (Jeannerod, 2006), incluindo tarefas como rotação mental de imagens corporais (Parsons et al., 1995). Mais, estudos em percepção musical correlacionam a ativação de córtices motores com a percepção de estruturas rítmicas da música, variando em nível de ativação de acordo com o grau de complexidade rítmica do estímulo (Grahn & Brett, 2007). Essas assunções predizem o Efeito Mozart, que consiste na melhoria temporária no desempenho de sujeitos em tarefas de raciocínio espaço-temporal, incluindo tarefas de rotação mental (Rauscher, Shaw & Ky, 1993).

Baseado nestas assunções, este estudo investigou se o desempenho de sujeitos (N = 36) em tarefas de rotação mental de imagens corporais teria alguma alteração após a escuta de peças musicais com diferentes níveis de complexidade rítmica e silêncio como condição controle. Os resultados demonstram que, apesar dos desempenhos dos sujeitos terem sido afetados pelas restrições biomecânicas dos seus corpos, sugerindo que a biomecânica corporal possui um papel limitador na cognição, o Efeito Mozart não foi observado, sugerindo que 1) a corporificação conceitual fraca pode não ser verdadeira para imaginação motora, e conceitos motores não estão ancorados em regiões cerebrais de modalidade-específica, 2) as amostras musicais utilizadas no presente estudo não foram adequadas para evocar ativação cortical o suficiente que resultasse em uma melhoria na performance na tarefa, ou 3) o Efeito Mozart se dá por razões distintas à ativação cortical de regiões cerebrais de modalidade-específica, como acréscimo em níveis de ativação e de humor ou por ser artefato da predileção por um estímulo (Chabris, 1999).

É, por fim, sugerido que pesquisas futuras empreguem técnicas de mapeamento cerebral, como Tomografia por Emissão de Pósitrons (PET Scan), Ressonância Magnética Funcional (fMRI), ou Eletroencefalograma (EEG), fortalecendo uma ou mais hipóteses que visam explicar a falha ao observar-se o Efeito Mozart neste estudo, identificando quais áreas cerebrais foram ativadas durante a exposição aos estímulos e/ou durante a realização da tarefa de rotação mental.

Palavras-chave: Teoria da Cognição Corporificada, corporificação conceitual, imaginação motora, percepção rítmica, Efeito Mozart

Resumo alargado

Após a revolução cognitiva, modelos de processamento de informação vieram a dominar teorias a respeito de como funciona a cognição humana (Gallistel, 2001). Em especial, a Teoria Clássica de Computação da Mente (CCTM) propõe que cognição, em sua essência, é computação sobre representações mentais através da manipulação de símbolos atômicos em virtude de propriedades sintáticas e valores semânticos que representam o mundo (Fodor, 1975). A CCTM também propõe que, haja vista que a mente humana opera através de computação, diversos sistemas como um robô humano, chips de silicone, um cérebro numa incubadora, etc., possam realizar computações sobre representações mentais (Fodor, 1981).

Ao longo das últimas décadas, entretanto, diversas investigações empíricas se debruçaram sobre a hipótese de que aspectos não neurais do corpo de um organismo podem ter um papel causal em tua cognição ou até mesmo constituir o processo cognitivo do agente. De acordo, a Teoria da Cognição Corporificada (ECT) diverge da CCTM no que diz respeito à dependência da cognição aos aspectos não neurais do corpo humano e também no que respeita à natureza das representações mentais: enquanto a CCTM propõe que a cognição é computação sobre representações mentais através de manipulação de símbolos abstratos, amodais e arbitrários, que não fazem referências às suas propriedades físicas, a ECT propõe que a representação simbólica não é amodal, ou seja, as representações simbólicas são perceptuais, estando ancoradas em sistemas de modalidade-específica do cérebro (Niedenthal, Barsalou, Winkielman, Krath-Grauber & Ric, 2005).

Logo, essas duas fortes suposições que emanam de descobertas empíricas da ECT foram investigadas no presente estudo, nomeadamente: **1)** aspectos não neurais do corpo de um organismo possuem um forte papel causal de limitação sobre a cognição; e **2)** alguns conceitos estão ancorados em regiões cerebrais de modalidade específica. No que respeita à suposição **1)**, podemos observar alguns exemplos de aspectos não neurais do corpo exercendo um papel causal de limitação na cognição, como o bico de um tucano e as posições mais lateralizadas de seus olhos que, por exemplo, diminuem o campo de visão do animal, impossibilitando-o de poder ter a experiência de enxergar em 3D (Martin & Osorio, 2007). No que diz respeito à suposição **2)**, de acordo com a ECT, conceitos são simulações/recriações de experiências passadas (Barsalou, 1999). Entretanto, duas teorias relacionadas a conceitos emanam da suposição **2)**, uma vez que há a teoria de que *todos* os conceitos são simulações de experiências passadas (coporificação conceitual forte) ou que *alguns* conceitos são simulações de experiências passadas, ancorados em sistemas de modalidade-específica do cérebro (corporificação conceitual fraca; Mahon, 2015). O presente estudo foca na corporificação conceitual fraca, *viz*. conceitos motores.

Alinhado à suposição **2)**, estudos em imaginação motora sugerem que nós utilizamos conceitos motores ancorados em regiões cerebrais de modalidade específica (os córtices motores) para

realizarmos a simulação de atos motores com o nosso corpo (Jeannerod, 2006). De mesmo modo, de acordo com uma vasta gama de estudos que investigam a *hipótese de equivalência funcional* entre imaginação motora e execução motora, regiões sobrepostas e análogas do córtex motor estão implicadas quando imaginamos, planejamos e executamos uma ação motora (Jeannerod, 1994).

Tarefas de cunho comportamental também têm sido aplicadas ao estudo da relação funcional entre imaginação e realização motora. Por exemplo, a tarefa de rotação mental de figuras do corpo humano consiste na simulação motora de nossos próprios movimentos corporais para ser realizada (Parsons et al., 1995). Para realizar essa tarefa, sujeitos tendem a realizar a rotação mental de uma figura do corpo humano, trazendo-a a uma posição que assemelhe à posição anatomicamente canônica do membro no corpo humano, como se estivessem a realizar uma rotação física de seus próprios corpos. Desta forma, imagens de membros orientados em graus de inclinação que refletem posições anatomicamente estranhas (por exemplo, imagens inclinadas em 180º em relação à posição canônica de 0º) tendem a ter um tempo de resposta (RT) maior e taxa de acerto (ACC) menor do que imagens que refletem posições anatomicamente normais e canônicas do membro no corpo (0º, por exemplo; Parsons, 1987a).

Mais, estudos sobre percepção musical correlacionam a ativação de regiões motoras do cérebro com a percepção de estruturas rítmicas da música, variando em nível de ativação cortical de acordo com o grau de complexidade de tais estruturas (Grahn & Brett, 2007). Essas estruturas rítmicas compreendem estruturas como a *métrica simples*, onde, por exemplo, o acento da batida ocorre ao longo de intervalos regulares (no caso de um compasso 4/4, o acento da batida sempre ocorre no início de cada grupo de quatro unidades de batidas), a *métrica complexa*, e a *não métrica*, em que os acentos das batidas ocorrem em períodos de intervalos irregulares (o acento da batida, neste caso, ocorre em distintos períodos, nem sempre ao início de cada grupo de cada quatro unidades de batidas). Em suma, a escuta de estruturas rítmicas métrica simples produz maior ativação em regiões motoras do cérebro do que a escuta de estruturas rítmicas métrica complexa ou não métrica (Grahn & Brett, 2007).

O aumento no nível de ativação cortical em regiões específicas do cérebro é uma das possíveis causas para a melhora temporária no desempenho de sujeitos em tarefas de raciocínio espaço-temporal, incluindo tarefas de rotação mental, como previsto pelo Efeito Mozart (Bodner, Mutfuler, Nalcioglu & Shaw, 2001). Mais especificamente, após escutarem a Sonata 448K de Mozart, sujeitos obtiveram melhores resultados em tarefas de raciocínio espaço-temporal, como por exemplo, a Paper-Folding and Cutting (PF&C), comparadas às condições controle (relaxamento e silêncio) e outros estímulos musicais considerados simples (por exemplo, música repetitiva de Phillip Glass). Entretanto, diversos estudos não reproduziram o efeito, e diversos outros atribuem o Efeito Mozart a um artefato de preferência e prazer do ouvinte ou em virtude de alterações em níveis de ativação e de humor evocados pela escuta musical (Chabris, 1999).

Com base nestas assunções, o presente estudo investigou se o desempenho de sujeitos (N = 36) em tarefas de rotação mental de imagens corporais teria algum acréscimo após a escuta de peças musicais com diferentes níveis de complexidade rítmica, nomeadamente, métrica simples, métrica complexa, e silêncio como condição controle, replicando, assim, o Efeito Mozart. Uma peça musical intitulada Space Katzle, pelo DJ Motorcity Soul foi selecionada. A versão original é uma peça musical cujas batidas e estruturas rítmicas permanecem inalteradas ao longo de toda a sua duração, sendo caracterizadas como estruturas rítmicas métrica simples. Esta versão foi, então, editada manualmente, onde as posições das batidas foram remanejadas, com o intuito de transformar a segunda versão em uma peça musical com estruturas rítmicas métrica complexa de acordo com o estudo de Bouwer, Burgoyne, Odijk, Honing e Grahn (2018).

Os resultados demonstram que, apesar do desempenho dos sujeitos terem sido afetados pelas restrições biomecânicas dos seus corpos, uma vez que os tempos de resposta aumentavam e as taxas de acerto diminuíam conforme o grau de inclinação da imagem aumentava, sugerindo, então, que a biomecânica corporal possui um papel limitador nas respostas às figuras corporais, o Efeito Mozart não foi observado, dado que o desempenho dos sujeitos na tarefa de rotação mental figuras relacionadas ao corpo humano não diferiu significativamente após sujeitos terem sido expostos aos estímulos auditivos. Também foi observado que os níveis de ativação psicofisiológica (arousal) diminuíram após sujeitos escutarem a versão métrica complexa ou permanecerem em silêncio, e os níveis de humor só se alteraram na dimensão vigor/atividade após sujeitos permanecerem em silêncio. Não foram observadas diferenças significativas nos níveis de valência entre os três estímulos, demonstrando que os sujeitos não demonstraram preferência por nenhum estímulo específico.

Para se explicar a falha ao replicar o Efeito Mozart no presente estudo, uma lista de hipóteses foi elaborada, sugerindo tanto que 1) a corporificação conceitual fraca pode não ser verdadeira para imaginação motora, e conceitos motores não estão ancorados em regiões cerebrais de modalidade-específica, 2) as amostras musicais utilizadas no presente estudo não foram adequadas para evocar ativação cortical o suficiente para resultar em uma melhora na performance dos sujeitos, ou 3) o Efeito Mozart se dá por razões distintas à ativação cortical de regiões cerebrais de modalidade-específica, como acréscimo em níveis de ativação e de humor em consequência da escuta musical ou por se tratar de um artefato da preferência e satisfação que o estímulo auditivo causa nos sujeitos (não observados nos resultados). Entretanto, dada a ausência de métodos de mapeamento cerebral, como PET Scan, fMRI, ou EEG, a conclusão à respeito de qual destas três hipóteses é verdadeira torna-se impossível, uma vez que não foi possível observar quais áreas cerebrais foram ativadas durante a escuta dos estímulos musicais e/ou durante a tarefa de rotação mental de figuras relacionadas ao corpo humano. A utilização de uma destas técnicas fortaleceria uma ou mais hipóteses que visam explicar a falha em observar-se o Efeito Mozart no presente estudo, pois assim seriam identificadas as áreas cerebrais que de fato foram ativadas durante a escuta dos estímulos auditivos e/ou durante a realização da tarefa subsequente.

Palavras-chave: Teoria da Cognição Corporificada, corporificação conceitual, imaginação motora, percepção rítmica, Efeito Mozart

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List of Abbreviations and Acronyms

1PP	First Person Perspective
3PP	Third Person Perspective
3D	Three-Dimensions or Three Dimensional
ACC	Accuracy
BA	Broadmann Area
BPM	Beats Per Minute
CCTM	Classical Computational Theory of Mind
CD	Idiopathic Cervical Dystonia
DB	Decibels
DC	Direct Current
DF	Degrees of Freedom
ECT	Embodied Cognition Theory
EEG	Electroencephalogram
EMG	Electromyography
ERAN	Early Right Anterior Negativity
ERP	Event-Related Potential
fMRI	Functional Magnetic Resonance Imaging
GIM	Guided Imagery and Music
HPA	Hypothalamic-Pituitary-Adrenal
HR	Heart Rate
kHz	Kilohertz
LAN	Left-Anterior Negativity
M	Mean values
MEG	Magneto Encephalography
MIQ3	Movement Imagery Questionnaire 3
MR	Mental Rotation

ms	Milliseconds
N	Number of subjects
PAC	Primary Auditory Cortex
PET	Positron Emission Tomography
PF&C	Paper-Folding and Cutting
PMd	Dorsal Premotor Cortex
POMS	Profile of Mood States
RSR	Respiration Rate
RTs	Response Times
RTM	Representational Theory of Mind
SAM	Self-Assessment Manikin
SCR	Skin Conductance Response
SD	Standard Deviation
Sig.	Significance Level
SMA	Supplementary Motor Area
STG	Superior Temporal Gyrus
TMS	Transcranial Magnetic Stimulation
VMIQ	Vividness of Movement Imagery Questionnaire

Introduction

Ever since we are young, the mere thinking of doing some ordinary tasks seems to be more unpleasant than others. Thinking of going to an appointment with the dentist, for instance, may not cause us the same excitement as imagining that there will be an important tennis match tomorrow and we will score the match-point after a 3-hour clash with the opponent. Whereas imagining a spoon excavator poking our teeth in order to remove soft caries sometimes makes us wince and shiver even before we lie down before the procedure begins, the mental image of scoring the match-point and consequently lifting the Roland-Garros[1] tournament's trophy may result in feelings of joy, excitement and a faster heart beat as a physiological body response. Although these are too extreme examples that relate mental imagery to physiological responses from the body, one may ask *why* does mental imagery elicit such bodily responses and *how* do these responses take place. In general, why does imagining our bodies in specific situations may lead us to specific feelings and bodily-reactions?

Apart from these physiological bodily responses that emerge when imagining an upcoming event or a physical action, imagining a bodily action relies on our own body features. Let's think about lifting the Roland-Garros' trophy again. Why do we usually imagine lifting the object upwards with both hands, and not sideways with our non-dominant hand only? Why do we usually estimate the weight and other attributes of the object (i.e., whether the trophy's handle is cold or the base is made of wood)? Why do we 'feel like' that we are moving our arms or having our teeth being poked when we are thinking about lifting the trophy or at the dentist, respectively, even when we are not at the dentist or in front of a podium, waiting for the trophy?

Although all questions raised above require different answers, by either imagining ourselves having our teeth being poked by a spoon excavator or lifting Roland-Garros' trophy and feel the excitement of it, we typically evoke mental imagery (Kosslyn et al., 1995a). Mental imagery is defined as a *quasi-perceptual* experience in which we simulate or re-create perceptual experiences across sensory modalities, in the absence of the appropriate external stimuli (Pearson et al., 2012; Thomas, 2019). As Kosslyn et al. (2001a, p. 635) point out, mental imagery occurs when perceptual information is accessed from memory, giving rise to experiences such as, as they describe, "seeing with the mind's eye', or "hearing with the mind's hear". Hence, as Kosslyn and Thompson (2000) argue, since mental imagery draws on mechanisms used in perception, some of the parts of the brain used in visual perception (i.e., seeing a picture) are used in visual imagination (visual mental imagery) (Farah, 2000; Kosslyn and Thompson, 2000; Behrmann, 2000); likewise, the auditory cortex is involved when we, for instance, remember the song from our favourite Pop-Rock band or when musicians imagine a new

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[1] The Roland-Garros tournament, also known as the French Open, is a major tennis tournament held every year between late May and early June at the Stade Roland-Garros, in Paris. The tournament is regarded as being the most important tennis tournament played on a clay surface, and is one of the four Grand Slam tournaments held every year, along with the Australia Open, Wimbledon and the US Open.

melody when they are about to write a new song (auditory mental imagery; Zatorre and Halpern, 2005). However, although mental imagery draws on mechanisms related to our perceptual system (Kosslyn et al., 1995a; Kosslyn et al., 2001a; Gallese and Lakoff, 2005), the processes underlying mental imagery should be distinguished from those involved in perception as such: firstly, perception, as Kosslyn et al. (1995a) define, is the registration of physically present input directly from our senses – sight, hearing, touch, smell and taste, whereas, as described above, mental imagery lacks this appropriate external stimulus; thus, perception does not require us to activate information in memory when the stimulus is not present, unlike mental imagery, in which we retrieve information from long-term memory to create or re-create experiences in our minds (Kosslyn et al., 2001a; Cumming and Williams, 2013).

Apart from relying on perceptual mechanisms, several studies have suggested that mental imagery also draws on mechanisms related to motor control and planning, giving rise to another category of imagery: motor imagery (Parsons, 1987a; Parsons, 1987b; Georgopoulos et al., 1989, Jeannerod, 1994; Parsons et al., 1995; Hamada et al., 2018). According to the motor imagery literature, some of the same parts of the brain used in the physical execution of a movement are also used when we imagine that we are executing a motor action (Jeannerod, 1994, 1995, 2001). Accordingly, studies that employed brain-mapping techniques have shown that a common network of brain motor centres, including areas such as, for instance, in the premotor and in the motor cortices when we carry out a motor action and when we imagine or plan to physically execute a motor action (Roland et al., 1980; Ryding et al., 1993; Parsons et al., 1995; Grafton et al., 1996; Porro et al., 1996; Gerardin et al., 2000). Returning to the trophy lifting example, according to the motor imagery literature, imagining oneself lifting a trophy consists of a simulation of the past experiences of lifting the trophy or similar objects, which takes into consideration the affordances we may have with the object, the biomechanical constraints of our body, the physical properties of the object, etc., in which brain areas activated during this imagery task overlaps those of motor execution (Jeannerod, 1994).

The hypothesis that mental imagery relies on perceptual and motor mechanisms has also been investigated through behavioral paradigms from Cognitive Psychology. Perhaps, one of the most investigated cognitive tasks that involve mental imagery is a mental rotation (MR) task (Shepard & Metzler, 1971). In order to carry out a MR task, subjects have to imagine a spatial transformation of one or more objects depicted on a computer screen or piece of paper at different orientations and degrees of inclination, and then mentally rotate the object(s) in order to match it (them) with a target stimulus or make a judgment about whether the objects are the same or mirror images (Hotstetter & Alibali, 2008). According to a wide range of studies, there is compelling evidence that some MR tasks relies on mechanisms involved in motor imagery, in special, when we carry out MR of of bodily-related pictures (Shepard & Cooper, 1982; Parsons, 1987a; Parsons, 1987b; Wexler et al., 1998). Likewise, studies that employed brain-mapping techniques (Parsons et al., 1995; Hamada, 2018) have also reported the activation of some of the same motor areas involved in motor imagery when subjects carried out MR of bodily-related pictures.

The empirical findings that mental imagery relies on the same mechanisms involved in perception and motor actions suggest that cognitive activities, such as visual and motor imagery, are *embodied* (Barsalou, 1999). In other words, according to *conceptual embodiment*, one way in which cognition can be embodied, concepts used in mental/motor imagery tasks are deployed through simulations of past experiences, in which it is theorized that *all* concepts are deployed this way (strong embodiment) or *some* concepts are deployed this way (weak embodiment). This particular simulation of past experiences relies upon systems of perception, action and introspection, in which some of the same neural substrates involved in these systems are recruited when a physical input is not available, visual/motor imagery seem to be a *modality-specific* process, as Niedenthal et al. (2005) claim. This account for cognitive activities departs from previous theories of mind, such as the Classical Computational Theory of the Mind (CCTM; Fodor, 1983), which claims that cognition is based on the computation of amodal, abstract and arbitrary symbols with semantic values and syntactic properties in a language of thought.

Apart from the claim that visual/motor imagery are modality-specific processes, the present study aims to approach the Embodied Cognition Theory (ECT) claim that the specific body we have plays a strong causal and *constraining* role in cognition. For instance, we have two eyes positioned where they are, which makes binocular vision possible and, therefore, allows us to have particular cognitive experiences (for instance, to see things in motion, to see things in depth, etc). Alternatively, if we had our eyes positioned elsewhere in the body (on the sides of our heads, like some birds have), it is possible to hypothesize that we would not have the same cognitive experience that we have due to the fact that our eyes are positioned where they are. We would probably experience vision differently than we currently do and, therefore, our visual perceptual would be different, we would perceive things in motion differently, we would have different patterns of eyes saccades when we read a book, our visual imagery of our favorite tennis player or even ourselves lifting the Roland-Garros' trophy would probably be different, etc. The body as a constraint on cognition has been also observed in imagery tasks, since biomechanical constraints of the body seem to play strong causal role in subjects' performance at tasks that supposedly rely on motor imagery (Parsons, 1987a, 1987b).

In line with the ECT assumption that simulations of past experiences take place in modality-specific brain systems for perception, action and introspection (Barsalou, Niedenthal, Barbey & Rupert, 2003), in which the motor areas seem to be involved in cognitive processing of motor imagery tasks, it has been observed that some of these motor areas are also implicated in music perception. More specifically, by employing brain-mapping techniques, it was found out that some areas in the motor cortices are involved in the processing of musical rhythms, since these cortical areas have been activated while subjects were exposed to distinct musical rhythms (Zatorre, Chen & Penhune, 2007;

Chen, Penhune & Zatorre, 2008a). More specifically, Grahn and Brett (2007) have found out that perception of rhythmic stimuli is correlated with distinct patterns of activation in the motor areas, in which stimuli with simple rhythmic patterns (Metric Simple) elicited higher cortical activation than stimuli with more complex rhythmic patterns (Metric Complex).

By taking into consideration that 1) according to conceptual embodiment, we run perceptual simulations in modality-specific systems of perception, action and introspection, in which some areas in the motor cortices of the brain are active during motor imagery tasks, and these simulations constitute and constrain cognitive experiences, affecting cognitive tasks, such as MR tasks of bodily-related pictures, and 2) music increases activation in sensorimotor areas, varying in degree of activation according to the rhythmic patterns a subject is exposed to, an interesting question then emerges: *does listening to music increase MR performance?*

In order to investigate the question elaborated above, the present study has been divided in four chapters: the first chapter is a literature review of the topics described above. The theoretical background chapter comprises a discussion of empirical findings that emerged from studies related to ECT, motor imagery and music perception. This chapter also focuses on the discussion of the mental imagery phenomena, describing the differences and similarities between visual imagery and motor imagery. Very importantly, this chapter also aims to show how MR of bodily-related pictures is linked with motor imagery processes through the discussion of empirical findings in the literature of this topic, suggesting that this specific task is accomplished through simulation of one’s own bodily movements. Finally, the findings of studies in the field of music perception in which activation in the motor areas has been found out are presented, as well as it is discussed the relationship between music and performance of cognitive abilities, in special, the influence of music in spatial reasoning tasks, namely, the Mozart Effect. The first chapter of this study, then, ends with the hypotheses raised in line with the findings from theoretical and empirical studies described in the chapter.

The second chapter of the present study describes the empirical study that was carried out. Subjects (N=36, mean age = 21.7, Standard Deviation: 3.08) performed a MR task under control condition (Silence) and experimental conditions (music with simple rhythmic patterns and music with complex rhythmic patterns, namely, Metric Simple and Metric Complex Music, respectively). This chapter describes methodological features employed in the present study, such as the process of stimuli selection, the procedure applied in the experiment, the selection of subjects, the instruments used to measure the power of the independent variables over the dependent variables, the technological apparatus and the experimental design.

Results are presented in the third chapter of this study. Statistical analyses are carried out and the results emerged are then discussed in the light of the theoretical and empirical content described in the first chapter. Finally, the limitations of the present study are reported and suggestions for future studies are made, followed by the conclusion, in the fourth and fifth chapters, respectively.

This study converges with distinct fields within the realm of Cognitive Science, such as Philosophy, Psychology and Neuroscience. The first chapter of the present study discusses the philosophical grounds of the ECT and the mental imagery phenomena, as well as it describes empirical studies that adopted behavioral paradigms from Cognitive Psychology or brain-mapping techniques from Cognitive Neuroscience. Having these findings as a base, the experiment adopts a behavioral paradigm often used in studies in Cognitive Psychology, a MR of bodily-related parts. Finally, based on the results emerged from the experiment, implications to ECT and to previous empirical studies described in the first chapter are discussed.

I. Theoretical background

1 Embodied Cognition Theory in Cognitive Science

In the past few decades, the role of the body and its non-neural parts[2] in cognition has led to a good amount of work within the scope of Cognitive Science. Works in areas such as linguistics (e.g. Lakoff and Johnson, 1980), cognitive psychology (e.g. Glenberg, 1997), philosophy of Mind (e.g. Varela, Thompson & Rosch, 1991), robotics (e.g. Maris & te Boekhorst, 1996), and neuroscience (e.g. Pulvermuller, 2013), have directed attention and emphasized the bias that an "(organism's) body plays in an organism's cognitive process" (Shapiro, 2007, p. 338), in which it has been argued that extra-neural parts of the body are literally part of the mind (Shapiro, 2010). In sum, the claim that 'cognition is embodied' has become one of the most discussed claims in Cognitive Science (Wilson & Golonka, 2013). However, this interest in the specific role of the body and its structural features in cognition is not particularly an avant-garde theory in Cognitive Science; on the contrary, ECT is often viewed as an alternative and a contrast to previous theories of how the mind works in Cognitive Science, in particular, the CCTM (e.g. Varela et al., 1991; Barsalou, 1999; Shapiro, 2007, 2010; Foglia & Wilson, 2013; Wilson & Foglia, 2017). The next topics of this section will thus approach the historical context of CCTM and ECT within Cognitive Science, and will describe some of the differences and similarities between them.

1.1 The Classical Computational Theory of Mind

The cognitive revolution in the 1950's changed the scientific and intellectual landscape, in which behaviorism had dominated experimental psychology for decades, since the beginning of the 20th century (Thagard, 2019). Back then, as Miller (2003) points out, it was proposed that psychology should be redefined as science of behavior, being restricted to examining the relation between observable stimuli and observable behavioral responses. The argument was that mental events were not publicly observable, and the only objective evidence available and that could be observed was behavior. Thus, topics such as mental events, consciousness and mental representations were then banished from scientific discussion (Gallistel, 2001; Miller, 2003; Thagard, 2019).

Along with works that criticized the behaviorist approach in areas such as linguistics (Chomsky, 1956) and psychology (Miller, 1956) and the subsequent redefinition of these areas, the emergence of disciplines such as neuroscience and computer science and the first works in artificial intelligence, new theories of mind based on complex representations and computational procedures began to be

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[2] Diverse terms have been used to refer to the claim that non-neural parts of the body play either a constraining or a physically constitutive role in cognition in the literature. Hereafter, terms such as "structural features of the body", "embodiment", "bodily structures", "bodily variation", "extra neural parts of the body" will exclusively refer to the role of the non-neural parts of the body in cognition, excluding the neural parts of the body, namely, the brain processes, from each one of these terms.

developed under the umbrella of an unifying and interdisciplinary field: Cognitive Science (Varela et al., 1991; Miller, 2003; Thagard, 2019).

After the cognitive revolution, information processing models came to dominate psychological theories of cognition (Gallistel, 2001). For instance, one of the mainstream accounts of cognition in philosophy of mind and Cognitive Science, the CCTM[3] proposes that cognition is, in essence, the manipulation of abstract atomic symbolic information in virtue of simple syntactic properties (Fodor, 1975), in which intelligent behavior is causally explained by Turing-style computations carried out on symbols that *represent* what they stand for (for instance, the symbol 7 represents the number 7; Piccinini, 2009). In other words, as Varela et al. (1991) describe, the CCTM consists in the hypothesis that cognition is computation over *mental representations*, adding to this that cognition is the manipulation of atomic symbols with semantic values that represent features of the world or represent the world as being a certain way through purely syntactic computations.

This computational process over mental representations can be exemplified as follows: The sentence MARY LOVES JOHN is composed by three atomic symbols, such as MARY, LOVE, and JOHN. Each one of these atomic symbols are primitive representations with semantic values, which can be combined according to syntactic rules, giving rise to complex representations, such as MARY LOVES JOHN (Fodor, 1975). Thinking in sentences like MARY LOVES JOHN, for instance, as Fodor (1989) points out, occurs in a *language of thought* (sometimes called *Mentalese*), a system of mental representations that proposes that thought has compositional structure that relies on systematic syntactic rules. Hence, the meaning of a complex representation - such as MARY LOVES JOHN – is a function of the meaning of each one of these symbols and the way they are combined according to a set of formal syntactic rules (Gallese and Lakoff, 2005; Rescorla, 2017). In sum, mental activity, as Fodor (2001) posits, occurs through Turing-style computation upon objects, such as symbols, in a system of finite set of mental representations, such as the language of thought.

In line with the Turing-style computation over symbols, the CCTM recognizes the possibility that, since the mind is *literally* a computing system, computation could be realized in different physical systems, such as a computing machine in a robotic body, a human brain, silicon chips, calculating machines, a brain-in-a-vat, disembodied spirits, etc. (Fodor, 1981; Rescorla, 2017). Since computation takes place over mental representations, these systems could all have mental states (Fodor, 1981).

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[3] The CCTM is a version of the Representational Theory of Mind (RTM), which states that mental states, such as thoughts, beliefs, desires, and perception have “intentionality”. In other words, these states refer to things or are about something. Such intentional states are the result of a functional relation between the cognitive agent and the symbolic propositional content of the mental states (Pitt, 2018). For instance, to *believe* that Donald Trump is the current president of the United States of America is the result of the relation between the agent and the propositional content that Donald Trump is the current president of the USA, which is different to the *desire* or *fear* that Donald Trump is the current president of the USA (although the mental representation is the same - that Donald Trump is the current president of the USA - to *believe* that Donald Trump is the current president of the USA involves a specific functional relation between the agent and the mental representation which is distinct to the *fear* that Donald Trump is the current president of the USA).

Under the CCTM perspective, mental representations are conceived as *abstract*, *amodal* and *arbitrary* symbols (Fodor, 1975; Gallese and Lakoff, 2005). More specifically, these symbols are abstract because the content of mental representations are abstract objects (i.e. properties, relations, propositions), amodal because these symbols make no reference to physical or sensory modalities (the amodal symbols that represent the color of objects in their absence are not the same of amodal representations of colors during visual perception), and arbitrary because the symbols are arbitrarily related to their referents in the world (words have no inherent relation to the objects, people, or commands – for instance, there is no reason why one symbol rather than another is used to represent the concept "table"; Glenberg & Kaschak, 2002; Foglia and Wilson, 2013; Nathan, 2014; Pitt, 2018).

The CCTM view dominated Cognitive Science to such an extent that it was often taken to be Cognitive Science itself in the 1960's and the 1970's, or "the only game in town" (Fodor, 1975; Varela et al., 1991). However, this status did not free CCTM from criticism. As it will be described in the next section, new ways of thinking about the mind have been developed throughout the last few decades.

1.2 4E Cognition

As observed in the last section, the CCTM states that cognition is computation over *mental representations*, occurring through Turing-style computation upon abstract, amodal and arbitrary symbols in a language of thought (Varela et al., 1991; Fodor, 2001). Accordingly, computation can be realized in different cognizing organisms, such as the human brain, silicon chips, etc. (Fodor, 2001). An organism's body, under the CCTM, is often viewed as "peripheral to understanding the nature of mind and cognition", according to Wilson and Foglia (2017, p. 1).

In the last few decades, however, the development of research paradigms have given rise to new ways of thinking about how the human mind works, departing from some of the tenets of the CCTM (Rowlands, 2010; Schiavio & van der Schyff, 2018). More specifically, these perspectives about the mind are inspired by and organized not around brain processes, but rather some "combination of the ideas that mental processes are embodied, embedded, enacted and extended", giving rise to 4E cognition (Rowlands, 2010, p. 14).

Although each one of the 4E's are supposedly grouped together as a "unitary alternative to classic, computational, cerebral, cognitivist approaches" such as the CCTM (Gallagher, 2017, p. 70), each one of them has different features and different perspectives regarding the weight of the concept of embodiment in cognition (Gallagher, 2011). The next few topics of this section will elucidate the characteristics of each one of the positions of 4E Cognition (Cognition as Embodied, Embedded, Extended and Enactive) in the light of the experiment proposed in the present study.

1.2.1 Embodied Cognition (ECT)

The general characterization of the ECT and the centrality of the extra-neural bodily structures for cognition that have been studied in the fields mentioned above are described by the *embodiment thesis* (Wilson and Foglia, 2017, p.7):

> "*Many features of cognition are embodied in that they are deeply dependent upon characteristics of the physical body of an agent, such that the agent's beyond-the-brain body plays a significant causal role, or a physically constitutive role, in that agent's cognitive processing*".

According to the embodiment thesis, as Foglia and Wilson (2013) point out, the non-neural parts of the body play a significant causal role in cognition through distinct roles in cognitive activity, such as a *constraint* on cognition or a *physically constitutive* for cognitive processes, as described next.

At a more general level, cognitive activity is significantly shaped by the specific structural features of an organism's body, *constraining* how the world is experienced by the agent (Dawson, 2014). By taking an example from another organism rather than the human beings, some birds, for instance, a toucan, are not able to experience 3D vision, due to the beak between its eyes and to the actual location of their eyes in their heads (Martin & Osorio, 2007). Some other birds, on the other hand, have a wide range of vision (for instance, an American Woodcock has a visual field of 360º in the horizontal plane and 180º in the vertical plane), allowing these species to detect predators/preys more easily (Jones, Pierce and Ward, 2007). As far as human vision concerns, however, we have two eyes positioned where they are, which makes binocular vision possible and, therefore, allows us to have particular cognitive experiences like seeing things in 3D, but as our visual field is not as wide as the American Woodcock, we are not allowed to experience 360º vision in the horizontal plane. Based on this example of how the position of our eyes may constrain our conscious experiences, as Shapiro points out (2004), the specific bodily structures of an organism account for similar experiences and conceptions of the world between conspecifics and differences between organisms with different bodily structures (e.g. humans can see in 3D, while toucans cannot; American woodcock can see in 360º, while humans cannot).

In line with Shapiro's (2010) claim, Wilson and Foglia (2017) draw attention to two implications that the body as a constraint may account for cognition. Firstly, some cognitive processes may be easier or more difficult, or even impossible, as a function of the specific body the cognitive agent has – understanding a sentence such as "Harry picked up and squashed the ball with his hand" might be easier to understand "Harry picked up and squashed the ball with his eye", since the human eye cannot materially pick up and squash any object, unlike the human hand (Glenberg & Kaschak, 2002). Secondly, bodily variation may account for variation in cognitive experiences among conspecifics – as it will be further described in the following sections of this study, subjects with limb amputations have slower response in tasks that demand spatial transformation of one's own body, such as MR tasks of bodily-related pictures (Nico, Daprati, Rigal, Parsons & Sirigu, 2004).

Further, Gallagher (2017) points out that the extra-neural parts of the body also have a constraining role in other higher cognitiVE tasks, such as, for instance, conceptualization. In line with this claim, Lakoff and Johnson (1999, p. 19) claim that the "peculiar nature of the body also contributes to conceptualization and categorization", very much reflected in metaphors. In this case, as the authors claim, metaphors are built based on our bodily experiences and rely on how our body is perceived in space, in which we use our bodies in space as a point of reference to construct spatial metaphors, e.g.: "What's up"; in this case, "up" is bodily-based and reflect to something, in English language, positive; differently, "I'm feeling down" has the word "down" as bodily-based too, and, in this case, would mean something negative. In sum, according to Lakoff and Johnson (1980/1999), these metaphors are considered as a bridge between embodied experiences and how we perceive our body in space and our conceptual knowledge. Alternatively, if we were flat, spherical beings, without any reference of what would mean spatial concepts such as 'front', 'down', 'up', 'back', we would not be able to construct these spatial metaphors, and processes such as conceptualization/categorization would be much different without these metaphors (Lakoff and Johnson, 1980).

Apart from the causal influences described by the 'body as a constraint' on cognition, Shapiro (2010, p.4) argues that "the body and the world play a constitutive rather than (just) a causal role in cognitive processing". In this case, in order to be considered an element that constitutes cognition, Shapiro (2010) claims that if this given element is central to cognition, then cognition would be different or would either fail to exist without its presence.

As an example of the structural features of the body playing a physically constitutive role in cognition, the specific shape of a bat's ears plays a computational role in echolocation (Dawson, 2014). More specifically, the bat performs high precision propagation of acoustic pulses through its mouth or nose at the ultrasonic frequency of 30 kilohertz (KHz), which, in turn, will situate the bat in the environment in order to detect its prey. Once the bat finds its prey, the bat employs different strategies to approach and capture it, such as, for instance, emitting ultrasonic frequencies out of the range of the prey's hearing (MacIver, 2009; Dawson, 2014). In sum, as MacIver (2009, p. 488) claims, "the conformation of skin and supporting tissue of the ear in the bat forms a computational device that solves a key problem in the localization of prey in three-dimensional space".

As observed, under the cognition as embodied perspective, non-neural bodily structures play a major constraining or constitutive role in perception and in many higher cognitive activities, such as reasoning, imagery, memorizing, decision-making, conceptualization, etc. (Lakoff and Johnson, 1980; Shapiro, 2010; Gallagher, 2011). The constraining and constitutive role that the non-neural parts of a body's organism will be further approached on later sections of the present dissertation, such as section 1.3, in which an interpretation of ECT is discussed, namely, conceptual embodiment – a view that states that concepts are simulations of perceptual, motor and introspective experiences, making the case for both constitutive and constraining role of the non-neural parts of the body in cognition - and section 3.6, in which empirical examples of how the bodily non-neural structures constrain motor imagery will be provided.

1.2.2 Embedded Cognition

On the embedded cognition view, the physical interaction between the body and the world plays a causal constraining role in the possible behaviors of organisms in an environment, since cognition deeply depends on the natural, social and cultural environment the agent is inserted in (Wilson & Foglia, 2017). The embedded cognition view relates to the ECT view described in the previous topic as both of them state that the experience of having a body with sensorimotor capacities plays a strong constraining role in cognition, as stated by the embodiment thesis; however, the scope of embedded cognition view stresses the nature of a body and how this body affects or is affected by the environment, and consequently, the cognitive experience that derives from this binding between body-brain-environment (Varela et al., 1991; Shapiro, 2010; Dawson, 2014).

The echolocation case described in the previous section can be seen as an example of how the coupling between environment and the organism's body can affect cognition. In that case, the bat relies on the shape of its ear to emit sonic waves in order to situate the bat in the environment. By receiving feedback from the environment, the bat is able to navigate through the environment and seek for its prey (Dawson, 2014). In sum, according to Rupert (2004, p. 4), the working hypothesis of *embedded cognition* is that "cognition depends very heavily, (…) in organismically external props and devices and on the structure of the external environment in which cognition takes place". Very importantly, though, Rupert's (2004) working hypothesis on embedded cognition does *not* entail that cognition can be extended to world, as stated by the extended thesis (this view will be approached in the next topic), but that cognition takes place in the brain as a result of the binding between brain-body-environment (Shapiro, 2010).

The embedded view of cognition has incorporated insights from the ecological psychology proposed by Gibson (1979), which assumes that cognition is a result of the interaction between a given organism and the environment this organism is inserted in (Hofstetter & Alibali, 2008). As an example of a constraining role in cognition, Gibson (1979) proposes the concept of affordances, in which the environment and its qualities and features allow us to perform certain actions with objects and with the environment. According to Hostetter and Alibali (2008), our ability to perceive emerge from the need to interact with the world, in other words, to engage in affordances with the environment. Thus, without the possibility of engaging in affordances in the environment, we would not be able to perform a number of potential actions important for survival, ultimately playing a constraining role in cognition.

In an example of how affordances relate to cognitive processes, Wheeler (2014) describes a complex mathematical operation: a pen and a paper provide people with affordances to write down mathematical operations and aid with the calculation process. Since the affordances provided by the pen and the paper when one carries out complex mathematical operations aid with the task, which probably would not have been possible to be carried out without these objects, a system of brain-body-pen-paper has played a causal role in the cognitive processing of adding numbers, facilitating cognition. Although the pen and paper provide subjects with the affordances to write information down on a piece of paper and aid with the complex mathematical operations, they are just resources that help with the task, and not "qualified as part of the cognitive architecture", since the mathematical operations are still carried out in the brain, in this case (Wheeler, 2014, p. 375).

1.2.3 Extended Cognition

According to Gallagher (2011/2017), this view emphasizes the environment and makes claims about the role of instruments, objects and things in the environment and how they constitute cognition. Under this view, instruments and devices outside of the body, such as calculators and notebooks (Clark, 2001) are part of the cognitive architecture. In sum, the extended cognition approach claims that the components of this system, instead of just playing a strong causal role in cognition, are *constitutive* of the cognitive process (Adams & Aizawa, 2008).

In the mathematical example provided in the previous section, the pen and the paper used for helping one to carry out a complex mathematical operation are considered constitutive of the mathematical operation, hence, part of the cognitive architecture involved in the task. In other words, cognition is *extended* beyond the brain into the world and the objects we utilize to solve cognitive tasks (Shapiro, 2010).

In line with the idea of the pen and the paper as playing a constitutive role in a mathematical operation, Clark and Chalmers (1998) claim that the role of certain environmental entities is functionally equivalent to those of internal cognitive states, and for that, these environmental entities should be regarded as part of our cognitive systems. The authors further exemplify this claim with the notebook example: when using a notebook, people could store information there, which will be available to consciousness in the future. In this case, as the authors point out, the notebook plays the role of our biological memory, eventually helping one to retrieve a piece of information in the future. In sum, on this view, cognitive systems extend beyond of the boundary of an individual's body, in which aspects of the environment may also constitute the agent's cognitive system, assuming that these cognitive systems are functionally equivalent to our bodily cognitive systems responsible for memorizing information, calculating mathematical operations, etc (Clark & Chalmers, 1998; Clark, 2001; Clark, 2008; Wilson & Foglia, 2017).

1.2.4 Enactive Cognition[4]

Proposed by Varela et al. (1991), under the enactive view, brain, body and environment are dynamically coupled at multiple levels, in a way that forms a highly structured dynamical system in which cognition is distributed across these elements (Gibbs, 2006).

Within this dynamical system, the relation between perception and action forms a perception-action loop, in which action contributes to perceptual processes and actions are substantially guided by our perception of the world, shaping cognitive processes. Thus, both are inseparable for cognition under the enactivist account (Varela et al., 1991; Shapiro, 2010; Gallagher, 2011). More specifically, Varela et al., (1991) claim that we have bodies with sensorimotor contingencies that interact with the environment, and this interaction between both results in an action-perception loop. Likewise, O'Regan and Nöe's (2001) account of visual perception states that visual perception does not consist in activation of neural representations in the brain after input of visual stimulus onto the retina. Conversely, O'Regan and Nöe (2001, p. 946) claim that the experience of vision is actually "*constituted* by a mode of exploring the environment", in which the interactions between the visual apparatus and the environment follow an organism's *sensorimotor contingencies*[5], *viz.* the characteristics of the visual apparatus and physical properties of the stimulus this visual apparatus is responding to, like hues of colors (sensory contingencies), and activities such as eye movements and other muscles of the body involved in seeing, like the orbicular muscles (motor contingencies). O'Regan and Nöe's (2001) account of vision perception is an example of this perception/action loop, since the authors claim that that vision is a way of acting, a mode of exploration of the environment mediated by our sensorimotor contingencies. In line with O'Regan and Nöe's (2001) account of visual perception, Varela et al. (1991, p. 174) claim that perception also contribute to the "enactment of this surrounding world": perception of a visual stimulus and the physical properties of this stimulus (e.g. the brightness of the sunlight) in turn influences our sensorimotor contingencies (e.g. the brightness of the sunlight may result in successive eye blinks).

O'Regan and Nöe's (2001) account of visual perception described above, as Gallagher (2011) points out, suggests that this coupling between sensorimotor contingencies and environmental affordances that accounts for visual perception replaces other accounts offered by traditional theories of mind in Cognitive Science, such as the CCTM, in which neural computations and mental representations are

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[4] The enactive approach for cognition has been used in different ways in the literature. Here, the first approach to enactive cognition, which gave rise to subsequent interpretations, drawn out by Varela et al. (1991) is described.

[5] As defined by Wilson and Foglia (2017, p. 15), sensorimotor contingencies are "a set of rules concerning how sensory stimulation varies as a function of movement"

accredited with much of the work involved in visual perception. In line with this claim, the enactive cognition approach proposed by Varela et al. (1991, p. 9) suggests that, rather than being neural computations over mental representations of the world, cognition is “the enactment of a world and mind on the basis of a history of the variation of actions that a being in the world performs”. In other words the enactivist account proposed by Varela et al. (1991) suggests the replacement of mental representations and neural computations over them by the history of embodied interactions between an organism’s physiology, its sensorimotor contingencies and the environment[6] (Myin & Degenaar, 2014; Wilson & Foglia, 2017).

Despite being often regarded as opposed to CCTM when it comes to explaining the nature of cognitive phenomena in various degrees (Shapiro, 2014) not all strands of 4E described in this section share the same opposition to all claims posited by the CCTM, in particular, the claim that cognition is constituted by *mental representations* over symbolic structures (Fodor, 1975, 1981; Thagard, 2019). Also, as Gallagher (2011) points out, there seems to be a few incompatibilities between these strands. In special, extended cognition seems to be consistent with functionalism and weak computationalism (Menary, 2010), leaving open the possibility of distinct systems realizing and constituting mental processes, such as calculators, notebooks, etc. “diminishing” any special role of the living body in cognition, since these instruments can augment or even take over bodily functions in cognition (Gallagher, 2017). This particular claim that cognition can be extended beyond the body is incompatible with ECT, for instance. As Wilson and Foglia (2017, p. 22) point out, although the non neural parts of the body can play a constitutive role in cognition and cognitive processing can be distributed across neural and non-neural systems of the body, “all non-neural resources are contained within the boundaries of the body”, meaning that these resources cannot be extended beyond the boundaries of the body. Also, and perhaps more debated within the 4E literature, Extended Cognition and Enactive Cognition are incompatible in the sense that, whereas the former would endorse a weak computationalism and an appeal to representations, the latter would dismiss them or would claim that they have a very limited role in cognition, being replaced by, as stated above, embodied interactions between an organism’s physiology, its sensorimotor contingencies and the environment, in an action-perception loop (Menary, 2010; Gallagher, 2011, 2017; Wilson & Foglia, 2017).

To bring this section to an end, apart from providing the reader with historical contextualization regarding ECT within Cognitive Science, the main reason why these different positions of 4E cognition have been described in this section is because the empirical findings from the experiment carried out and described in the present study may not necessarily shed light on all of them or they will not be on the foreground of discussion of the empirical findings of the present study. Thus, it is important to pin down what conclusions can be derived from the particular experiment carried out in

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[6] Although the first proposal of enactive cognition (Varela et al., 1991) replaces computation over mental representations by history of embodied interactions, not all enactive approaches discard neural computations over mental representations completely (e.g. Hutto & Myin, 2013).

the present study in the light of the description of the components of 4E cognition above. As it will be further described in the objectives and hypotheses section of this dissertation, one of the hypotheses raised for the experiment carried out in the present study specifically relates to the claim that an organism's non-neural body parts plays a constraining role in cognition, a central tenet of ECT described in 1.2.1. Also, as it will be observed in the following section, conceptual embodiment may also shed light on the ECT tenet that the non-neural parts of the body can play a constitutive role in cognition as well. Finally, although some of the central tenets from other 4E strands are seen as important landmarks for the study of the role of an organism's non-neural body parts in cognition and these strands may also relate to conceptual embodiment (as it will be briefly described in the next section, Embedded and Enactive cognition may also relate to conceptual embodiment) they will not be on the foreground of the discussion of the empirical findings of the present study.

1.3 Conceptual Embodiment and the CCTM

Firstly, departing from CCTM's claim that the mind is literally a computer described in the last section, the embodiment thesis highlights the dependence of cognition upon bodily characteristics, in which the body plays a constraining or constitutive role in cognition (Wilson & Foglia, 2017). Given this emphasis on the influence of aspects of the bodily movements and the organism's body anatomy on cognition, the embodiment thesis challenges the 'mind is a computer' claim in terms that computation over mental representations can be realized in physical systems other than an organism's body (Tirado, Kathin-Zadeh, Gastelum, Jones & Marmolejo Ramos, 2018). For instance, as Gallagher (2011) claims, according to cognition as embodied, the brain-in-a-vat[7] thought experiment would fail: as Damasio (1994) points out, in order to be able to replicate the same conscious and phenomenological experiences of an embodied brain, the brain in a vat would have to receive the same inputs the embodied brain receives, including biological inputs (e.g. hormonal), which are a subset of interactive body-brain systems, and not the product of brain processes alone (Cosmelli & Thompson, 2010). Even if the supercomputer were able to provide the brain with the necessary inputs to replicate human consciousness, this would suggest that the vat could be regarded as a surrogate body and "'body-type' inputs are required for a normally minded brain after all" (Damasio, 1994, p. 228). Shapiro (2010) also describes another inconsistency between the brain-in-a-vat and cognition as embodied, more specifically, the physically constitutive role a body might have in cognition. As stated in the ECT section of this study, if the structural features of an organism's body are constituents of cognition (e.g. the shape of the bat's ears in echolocation), then "the brain alone does not suffice for

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[7] In short, as Thompson and Cosmelli (2011) describe, the brain-in-a-vat is a thought experiment that consists of a mad scientist removing a human brain from a human body and placing it in a vat, connecting its neurons to a super computer that would simulate reality. This disembodied brain-in-a-vat would then continue to have normal conscious experiences, since the computer provides the brain with electrical impulses that an embodied brain actually receives and simulates the interaction between the brain and the environment. All in all, the main point of the argument is that the brain alone suffices for creating consciousness, provided it has the appropriate inputs and connections to the external environment.

cognition" (Shapiro, 2010, p. 162). However, if the envatted brain suffices for cognition, then it would be the case that the brain alone suffices for cognition, and the constitutive role of the body in cognition must be false. Conversely, if the constitutive role of the body in cognition is true, then the brain alone would not suffice for cognition (Shapiro, 2010).

Another major distinction between the CCTM and the ECT that has been widely approached and discussed, especially in the 4E cognition literature (e.g. Barsalou, 1999; Barsalou, Simmons, Barbey & Wilson, 2003; Shapiro, 2014; Gallagher, 2017), is the nature of mental representations. As Gallagher (2011) points out, not all strands of 4E cognition (embodied, embedded, extended and enactive) share a common opposition to mental (symbolic) representations. On the contrary, as Niedenthal et al. (2005, p. 185) claim, the processing of mental content may involve the computation of "internal symbols of some sort" in some of these approaches.

As observed in section 1.1, the CCTM proposes that high level cognition, such as categorization, memory, language comprehension, etc. is performed by abstract, arbitrary and amodal symbols, bearing arbitrary relations to physical or sensory modalities that produced them (Fodor, 1975; Pylyshyn, 1984; Barsalou, 1999; Niedenthal, et al., 2005). For example, when someone sees the words BLUE CAR on a piece of paper, the information perceived from the visual input is sent to the visual area responsible for translating the written script, the visual word form area (Dehaene & Cohen, 2011), into a new representational structure with amodal symbols, such as, for instance, feature lists. This feature list consists of a functional symbolic system of words represented in a language of thought that describes the blue car – the car is a physical object, it is a machine, it has engine, it has wheels, it has seats, it has a color, in this case, blue, and so on. The mental representation of the blue car, then, involves the processing and combination of these symbolic amodal descriptions of the object. As a result, the representation of a BLUE CAR = the symbol "physical object" + the symbol "machine" + the symbol "engine" + the symbol "wheels" + the symbol "seats" + the symbol "blue". (Fodor, 1983; Pylyshyn, 1984; Barsalou & Hale, 1993; Barsalou, 1999; Barsalou et al., 2003). In sum, in the concept processing, according to CCTM, the input information, in this case, the written words "BLUE" + "CAR" are transduced into a new representational language, the language of thought, which is inherently non perceptual (Barsalou, 1999). Thus, within this account for conceptual processing proposed by the CCTM, the sensory system is regarded as being a receptor of input of representations from the external world and the motor system typically allows for behavioral output (Niedenthal et al., 2005; Foglia & Wilson, 2013).

In contrast, conceptual embodiment proposes that concepts are simulations of perceptual experiences grounded in their physical context, in modality-specific systems of the brain (Barsalou, 1999; Mahon, 2015; Niedenthal et al., 2005). More precisely, Barsalou (1999) proposes that, instead of computing representations of amodal symbols that make no reference to physical or sensory modalities and that are arbitrarily related to their referents in the world, cognitive representations are inherently *perceptual*. In other words, instead of amodal symbols, Barsalou (1999) claims that mental representations are grounded in *perceptual symbols*, neural representations stored in sensorimotor systems that represent schematic components of perceptual experience and arise across "sensory systems that underlie perception of a current situation, motor systems that underlie action, and introspective systems that underlie emotion, motivation and cognitive operations" (Niedenthal et al., 2005, p. 186). In sum, Barsalou (1999) proposes that the transduction between a sensory input (e.g. a visual representation of a BLUE CAR) to amodal representations in a language of thought is not necessary.

As Barsalou (1999) describes, during perceptual experience, information about perceived events in the environment and in the body (online processing) are captured by systems of neurons in sensorimotor areas and are stored in long-term memory, as perceptual symbols. However, since this storage of information is selective, not all information present in the perceived event may be stored; hence, the perceptual symbol represents only schematic components of the perceived experience, and therefore, can be biased (Barsalou et al., 2003). The symbol formation process can operate on more than one modality aspect of the perceived experience, such as vision, audition, haptics, olfactation and gustation. This multimodal representation system then supports diverse forms of simulation across distinct high-level cognitive processes, such as imagery, conceptualization, memory, etc. (Barsalou, 1999; Barsalou et al., 2003; Barsalou, 2008).

The conceptual processing of BLUE CAR can also be used as an example of simulation of previous perceptual experience. In order to comprehend a concept's meaning while we read the words BLUE CAR on a piece of paper, apart from employing the visual word form area (Dehaene & Cohen, 2011) we run a mental simulation of blue car that we have seen in the past, and the sensory (in this case, visual) representation of the blue car is activated. As Barsalou et al. (2003) describes, when we see a blue car for the first time, neurons in modality-specific systems capture the visual representation of the car once the stimulus is perceived and store this visual information of the blue car in memory. The set of features of the blue car that was originally perceived at first (e.g. the car is blue, it has four wheels, it has seats, it has windows, etc) is then partially reactivated in the absence of the visual stimulus of a blue car, through simulation (as noted in the last paragraph, perceptual symbols only provide with a schematic representation of perceptual components of a BLUE CAR, since simulations are always partial and contain distortions). Apart from retrieving the features of the blue car that we perceive when we see the object from memory, we may also simulate the car being driven by us, since the object provides us with specific affordances. As it is multimodal, we may also simulate the sounds of the blue car's engine, the smell of the smoke being released by its exhaust pipe, etc. The perceptual simulation of a BLUE CAR during conceptual processing, according to conceptual embodiment and unlike the framework proposed by CCTM, in which a sensory input is transduced into non-perceptual amodal symbols in a language of thought, ‘approximates’ the simulated concept to the actual perception of BLUE CAR (Barsalou, 1999).

According to the description of conceptual embodiment provided in this section, conceptual embodiment may fit into the cognition as embodied, cognition as embedded and enactive cognition positions within 4E cognition, in which examples of body as a constitutive or body as a constraint on cognition (embodied), the binding between world-brain-body playing a causal role in cognition (embedded), and perception being a process of interaction between agent and the world in an action-perception loop can be observed (enactive). More specifically, simulations, as Barsalou (2008, p. 618) defines, are “the reenactment of perceptual, motor and introspective states acquired during experience with the world, body and mind”. Since reenacted experiences reflects on the interaction between the world, the body and the mind, these three elements can be seen as *constituents* of perceptual, motor and introspective states that underlie simulations. Accordingly, then, since simulations rely on the perceptual experiences, motor and introspective experiences we have, it seems like these experiences consequently shape the concepts we possess. In other words, conceptual processing is carried out through simulations (Barsalou, 1999); if simulations are the reenactment of perceptual, motor and introspective experiences, then concepts are the reenactment of these experiences. Since the kinds of perceptual, motor and introspective experiences we have shape conceptual processing, and these experiences are shaped by the binding world-body-mind, it is plausible to say that the body embedded in an environment *constitutes* conceptual processing. For instance, the BLUE CAR conceptual processing does not entail that a global car description across all experiences with car we have had in the past are going to be delivered, but rather, a specific experience we have had with a blue car in the past (Barsalou, 2003). Also, as Barsalou (1999) points out, when storing perceptual symbols while viewing a blue car, for instance, a subject’s selective attention focuses on a few aspects of the object (e.g. the color, the wheels, the doors, etc.); as a result of this approach, the perceptual records of the blue car are integrated spatially, according to the aspects of the object the subject’s selective attention focuses on. In sum, the concept of BLUE CAR seems to be *constituted* by the information deployed in simulations of the kinds of experiences we have had in the past related to blue cars.

Conceptual embodiment also makes the case for the constraining role of the body in cognition. First, as Barsalou (1999) claims, perceptual symbols systems change according to bodily systems. For instance, Barsalou (1999) argues that since conceptual system is grounded in experiences, and these experiences are shaped by bodily systems embedded in an environment, different animals that have different bodily and perceptual systems are likely to have different conceptual systems. Likewise, an infant’s perceptual system, which develops throughout time, is likely to be different to an adult’s. Also, both affordances and bodily constraints are likely to play a role in simulations and, consequently, conceptual processing. As Barsalou (1999, p. 594) claims, “a constraint arises when a schematic perceptual symbol cannot be applied to a simulated entity”. For instance, the simulation of "driving my lamp cautiously" results to be more difficult than "driving my car cautiously", since the schematic perceptual symbols of a lamp can hardly be applied to the simulation of "driving (something) cautiously". A lamp does not provide with the affordance of being driven. On the other hand, in the "driving my car cautiously", the schematic perceptual symbol of the car can be applied to the simulated entity of "driving (something) cautiously", due to the affordance that can be realized with the car and by the subject.

Two degrees of conceptual embodiment have been drawn out: first, *strong embodiment* entails that "all aspects of all concepts are represented in a modality-specific format", leaving no space for abstract, modality-neutral representations; conversely, *weak embodiment* means that *some* concepts are grounded in modality-specific areas, while others are "also represented at an abstract (or amodal), modality-independent level" (Mahon, 2015, p. 420). Whereas the former account of embodiment claims that perceptual symbols located in modality-specific systems of the brain account for higher cognitive processes, in which these symbols are acquired during online cognition and later used in offline cognition through simulation (Niedenthal et al., 2005), the latter is often recognized as a 'hybrid' sort of representational processing, in which amodal symbols may also be grounded in modality-specific systems and linked to modality-specific representations (Mahon, 2015). This grounding, according to Pulvermüller (2005), is done through 'neural cell assemblies', cortical areas responsible for binding information from different semantic representations. Finally, connecting with the constitutive or constraining roles that the body may have in conceptual processing highlighted in the last paragraph, according to strong embodiment, the body embedded in an environment plays a constitutive role in simulations that, in turn, underlie all concepts; similarly, bodily structures then constrains simulations for all concepts. Alternatively, the body embedded in an environment would constitute the simulations that underlie some concepts, and the body would constrain simulation just for some concepts as well, according to weak embodiment.

Niedenthal et al. (2005) describe the pros and cons of the CCTM and the conceptual embodiment accounts for the nature of concepts. First, on the one hand, as the authors claim, the CCTM lacks empirical evidence that states that the brain contains amodal symbols. Niedenthal et al. (2005) point out that the arguments in favor for the existence of amodal symbols and their role in cognition come from theoretical assumptions of how the mind might work, rather than empirical evidence. On the other hand, in the last few decades, it has been observed a great amount of empirical work that suggests that at least some concepts and higher cognition processes are grounded in modality-specific systems for perception, action and introspection, in other words, concepts and cognitive processes are grounded in their physical context and the *format* of cognitive representations is modality-specific (Wilson, 2002; Barsalou et al., 2003; Niedenthal et al., 2005; Foglia & Wilson, 2013; Mahon, 2015). Next section will discuss some of these empirical works in conceptual embodiment.

1.3.1 Empirical findings in Conceptual Embodiment

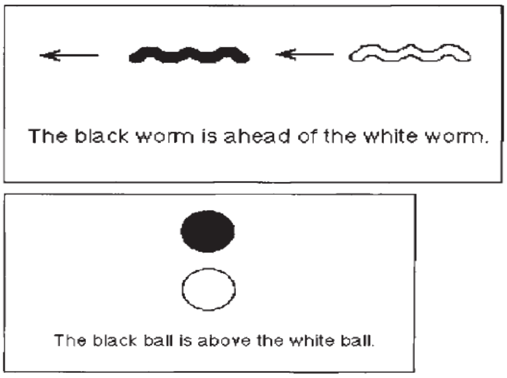
Most of the findings that provide the hypothesis that, at least, some concepts are grounded in modality-specific systems of the brain with suggestive evidence come from distinct Cognitive Neuroscience studies that have observed the neuronal activation of modality-specific areas for perception and action in the brain while subjects undergo some cognitive tasks. For instance, through an fMRI, Hauk et al. (2004) observed that, when presented with action words related to face, arm or leg actions, the Primary Motor Area and the Premotor Cortex involved in tongue movements, finger movements and foot movements were activated. By employing a PET scan, Grafton, Fadiga, Arbib & Rizzolatti (1997) observed that, whereas naming a tool silently activated the Broca's area, when subjects silently observed the tool or when they silently named the use of the object (e.g. HAMMER = hit the nail), the left Dorsal Premotor Cortex (PMd), the left Ventral Dorsal Premotor Cortex and the left Supplementary Motor Area (SMA) were activated, suggesting that neural areas activated when we physically manipulate the object are also activated to understand the object semantics. Simmons, Martin and Barsalou (2005) observed that the right Insula/Operculum and the left Orbitofrontal Cortex, both areas implicated in gustatory processing, were activated when participants merely observed the pictures of foods. Finally, through an fMRI, Fehr, Code and Herrmann (2007) observed that when subjects did different arithmetic operations of different levels of complexity, such as addition, subtraction, multiplication and division, the cortical network involved in finger movements.

In line with the findings described above, it has been reported that lesions in modality-specific systems produced deficits in categorical knowledge. For instance, in a lexical decision task with action verbs, nouns with strong visual associations and pseudo words, Neininger and Pulvermüller (2003) observed that subjects with right frontal lesions (areas involved in motor control) had worse performance at the lexical decision task when exposed to action verbs compared to nouns with strong visual associations. Conversely, subjects with lesions in the right Temporo-Occipital Areas (a visual area) had the opposite pattern of performance. Likewise, subjects with motor neurone disease showed more impaired comprehension and production of verbs compared to nouns (Bak, O'Donovan, Xuereb, Boniface & Hodges 2001). In sum, these findings corroborate with the claim that, in order to carry out these tasks described above that required offline processing, we rely on the same modality-specific systems that were once engaged during an online experience with a given object; therefore, we carry out different forms of simulation grounded in those systems, in which lesions in modality-specific systems may result in selective impairments in cognitive processing (Barsalou, 1999; Barsalou et al., 2003; Niedenthal et al., 2005; Barsalou, 2008).

Notwithstanding, the amodal architecture proposed by the CCTM has its own advantages, as some argue (e.g. Niedenthal et al., 2005, Mahon & Caramazza, 2008). For instance, Niedenthal et al. (2005, p. 186) argue that since representations employ amodal symbols through feature lists, propositions, semantic networks, etc., expressing the "content knowledge across different domains of knowledge, from perceptual images to abstract concepts" seems to be easier under the CCTM, especially abstract concepts, compared to conceptual embodiment. Although it has been a matter of criticism and skepticism, perhaps posing the most significant threat to the account that all concepts are grounded in modality-specific systems (e.g. Mahon and Caramazza, 2008; Mahon, 2015), the processing of abstract concepts has also been the scope of much work under conceptual embodiment (Shapiro, 2014; Kaschak, Jones, Carranza & Fox, 2014). As Kaschak et al. (2014) claim, the overall idea behind the conceptual processing of abstract concepts relies on the assumption that abstract concepts are "grounded in particular domains of concrete experience" (p.122), in which they could be represented metaphorically (Lakoff and Johnson, 1980) or through simulations (Barsalou, 1999). Some studies in Cognitive Psychology have addressed the hypothesis that abstract concepts are mapped to domains of concrete experiences.

For instance, the concept TIME is grounded in spatial representations around one's body, as Shapiro (2010) argues. By employing a priming paradigm, in which both English and Mandarin speakers had to respond true or false to target sentences (e.g. March comes *earlier* than April) after exposure to horizontal and vertical primings (Figure **1.1**). Boroditsky (2001) found out that TIME is described as having horizontal dimensions (front = future, back = past) for English speakers, and vertical dimensions for Mandarin speakers (up = future, down = past). Likewise, exposure to abstract concepts with an emotional valence, such as PEACE, is correlated with typical body responses (Pecher et al., 2011). In experiments where subjects had to move their arms toward or away from the stimulus according to the emotional valence it represents with no prior instructions given, when abstract concepts with positive valence were displayed on the screen, participants always made an arm movement towards the screen (e.g. ENJOYMENT), and the opposite pattern was observed for abstract concept with negative valence (e.g. ANGER; Chen and Bargh, 1999).

Despite these studies, it seems that the claim that the conceptual processing of concrete nouns and action verbs are grounded in modality-specific systems is clearer compared to the processing of abstract concepts, since, due to the large number of abstract concepts, it is not feasible to claim that they can all be represented by perceptual simulations based on concrete experience (Barsalou, 1999). In other words, it is not feasible to investigate whether strong embodiment is true or not, due to the large number of concepts. As such, findings from Cognitive Neuroscience still cast doubt on whether the conceptual processing of abstract concepts is actually grounded in modality-specific systems. In a Meta-Analysis study, Wang, Conder, Blitzer & Shinkareva (2010) observed differences in neural representations for concrete and abstract nouns. Whereas it was observed that the processing of concrete nouns elicited the engagement of the perceptual system, the latter elicited greater engagement of the brain areas involved in the verbal system, such as the inferior frontal gyrus and middle temporal gyrus. The same distinction in terms of neuronal activation in processing concrete and abstract concepts was observed in other studies that employed fMRI techniques (e.g. Pulvermuller, 1999; Shallice and Cooper, 2013).



The black worm is ahead of the white worm.

The black ball is above the white ball.

Figure 1.1: Examples of horizontal spatial prime (top) and vertical spatial prime (bottom). Retrieved from Boroditsky (2001).

Bearing in mind this struggle in accounting for conceptual processing of abstract concepts as grounded in modality-specific systems, 'middle ground' theories of conceptual processing have been raised in order to account for the processing both amodal symbols and modality-specific representations during conceptualization. With *grounding by interaction,* Mahon and Caramazza (2008) claim that, although all concepts are represented at an abstract level, sensory and motor information would only provide some concepts with relational context and grounding this abstract symbol with the physical world. In other words, concepts *could be* modality-specific representations, but they *do not necessarily have to be* modality-specific representations. For instance, the concept BEAUTIFUL is abstract, and has no specific physical referent in the world, since people can be beautiful, objects can be beautiful, words can be beautiful. Hence, as Mahon and Caramazza (2008) claim, whether modality-specific systems may be activated when one thinks something like "That mountain is beautiful", the physical referent of the mountain can be instrumental for the instantiation of the concept BEAUTIFUL, but that does not mean that the concept BEAUTIFUL itself is grounded in modality-specific systems or is represented in a modality-specific format.

Concrete concepts are also targeted by the grounding by interaction framework (Mahon & Caramazza, 2008). For instance, the concept DOG can be associated to a wide range of dog pedigrees (e.g. German Shepherd, Chihuahua, Stray Dog, Poodle). Since we run perceptual simulations in order to understand sentences and not computation over amodal symbols (Barsalou, 1999), understanding sentences such as "The dog jumped over the chair" or "The dog is hidden behind the wardrobe" would evoke different simulations of past experiences that we have had with dogs. Whereas in the first sentence it is typically easier to imagine a German Shepherd carrying out the action due to its size and strength, in the second sentence the Poodle is typically instantiated to the concept of DOG and being able to hide in narrow spaces. Thus, two distinct concepts of DOG are instantiated according to the sentence. Conversely, according to the grounding by interaction framework, the same abstract concept of DOG is deployed in both cases, despite the physical attributes of the DOG being different in the two sentences. In sum, although we have had experiences with dogs in the past and these experiences might be grounded in modality-specific systems, the concept of DOG itself may not be constituted by modality-specific representations. What the grounding by interaction proposes is that the concept of DOG is constituted by abstract representations and these abstract representations may be generalized across our modality-specific representations of dogs (Kaschak et al., 2014).

In line with the grounding by interaction framework raised by Mahon and Caramazza (2008), Louwerse (2008) and Louwerse and Connell (2011) are more specific in terms of pointing out the stages at which abstract and sensorimotor processes take place during conceptualization: whereas abstract information is processed at earlier stages, in which the concept input will be interpreted, and sensorimotor information is used at later stages of language processing, which will provide further detailed representation of the concept (Kaschak et al., 2014).

The assumptions from conceptual embodiment and CCTM presented in this section have been examined in the last few decades through the employment of different research methods and paradigms by distinct areas of Cognitive Science, such as Cognitive Psychology and Cognitive Neuroscience, for instance. The following sections of this dissertation will discuss some of the findings that emerged from investigations about mental/motor imagery in the light of weak conceptual embodiment and the ECT discussed so far.

2 Mental Imagery

2.1 The mechanisms of visual mental imagery

Mental imagery is a topic that has been exhaustively studied throughout the centuries by distinct fields, from the ancient Greek philosophers (e.g. Plato and Aristotle) until more recent achievements in the development of Brain-Computer interface devices. Although somewhat related, most of these findings go beyond the scope of the present study. Thus, this section will specifically discuss the mechanisms involved in visual mental imagery and the distinct accounts of visual mental imagery that can be found in the Cognitive Science literature.

First, as pointed in the introductory notes of the present study and in last section, conceptual embodiment questions whether cognition is made up of computation of amodal symbols that bear no correspondence to the referents they stand for; in other words, these amodal symbols would have no link with their sensory origin, being considered “raw” data that would be transduced into a code in a language of thought format (Fodor, 1975; Pecher, 2013). Adding to that, conceptual embodiment claims that concepts are grounded in modality-specific areas of the brain, as a result of simulations of past perceptual experiences (Barsalou, 1999). With the emergence of Cognitive Science, the debate around mental imagery has been about the type of code and the content conveyed by the images (Iachini, 2011), giving rise to distinct theories about the imagery phenomena.

In terms of visual mental imagery, Pylyshyn (1973, 1981) proposes that imagery has a language-like, abstract and discursive format, in which images are like linguistic descriptions of visual scenes with no spatial properties of their own (Pylyshyn, 2003; Thomas, 2019). Accordingly, Pylyshyn (1981) claims that images and words derive from the same code, expressed by abstract and amodal symbols in a language of thought architecture. Hence, according to this framework, imagery follows the same steps as other cognitive functions such as memory, language and thought, in which perceptual information is transduced into a non-perceptual representational language made of abstract and amodal symbal that are then computed (Pylyshyn, 1999). This process, as Pylyshyn (1978) points out, is independent of simultaneous activation of early visual processing areas, since these areas are *cognitively impenetrable* and imagery is *cogntivitely penetrable.*[8] Thus, under this perspective offered by Pylyshyn (1973, 1981), the perceptual systems (in this case, the early visual processing systems) are separated from cognitive processes (imagery) and work according to different principles (Iachini, 2011; Foglia and Wilson, 2013).

This account of mental imagery provided by Pylyshyn (1980) has been, in parts, confronted by other theories of imagery. First, instead of being processed by the same unitary system, Paivio's (1971, 1986) *dual coding theory* suggests that language-based and image-based stimuli are processed by different systems, known as *logogens* (for propositional discrete symbols that represent linguistic information) and *imagens* (for percept-like symbols that represent perceptual information). Visual mental imagery would belong to the latter group (Jeannerod, 1995; Iachini, 2011). In line with the concept of *imagens* proposed by Paivio, according to the analog theory, mental representations are, up to a certain extent, like pictures, or *quasi-pictorial*, sharing spatial properties and key elements that actual pictures have (Kosslyn, 1980; Kosslyn, 1981). The analog theory does not question particularly whether propositional representations with amodal/abstract symbols are deployed in imagery, but whether these symbols provide a reasonable account of imagery alone (Iachini, 2011). It is proposed by the analog theory that these propositional representations are stored in long-term memory in a format of amodal symbols (responsible for abstract information about the image) along with analog (literal) symbols (responsible for information about the shape of the image and other spatial

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[8] On the one hand, as Pylyshyn (1999) claims, early visual processes are cognitively impenetrable as they are inflexible and autonomous from people's beliefs and goals. For instance, in the case of visual illusion, although sometimes we reach to the conclusion or we are told that a particular image is an illusion, when we look at the image again we still feel deceived by it. On the other hand, imagery is considered as cognitively penetrable, since, according to Pylyshyn (1981), imagery is the symbolic representation of our beliefs, goals and so on (in this regard, when people imagine something, they use their tacit knowledge to simulate what would happen in the real world according to their beliefs).

attributes)[9]. These symbols give rise to conscious mental images in short-term memory, maintained in the visual buffer, a functional structure that comprises cortical areas involved in vision and topographically organized, which is responsible for depicting the spatial structure shape of an image and preserving the distances between the parts of the referent object (for instance, when we imagine a table, the referent object has four edges. The visual buffer depicts the spatial structure of the imagined table and preserves the distances between the edges of the object; Kosslyn, 1980, 1981, 1983, 2005; Iachini, 2011). The image generated in the visual buffer is perceived and processed by the visual system along two pathways: one runs from the Occipital lobe ventrally to the Inferior Temporal lobe, whose areas are responsible for processing image features such as shape, color and texture, while the other runs in the dorsal pathway to the posterior parietal lobe, being responsible for the spatial properties of the image (i.e. positions of the image in space and comparison between spatial location of two images). Thus, according to the analog theory, mental images are "reconstructed and processed in the visual system, (…) being percept-like representations similar that bear similarity with corresponding external referents" (Iachini, 2011, p. 7).

Findings from Cognitive Neuroscience provide suggestive evidence that visual mental imagery shares common neural substrates as visual perception and provide a clear picture of the specific cortical areas involved in both. The relation between the mechanisms involved in both visual perception and visual mental imagery has been investigated through neuroimaging techniques, such as PET scan (Kosslyn, Thompson, Kim & Alpert 1995b), fMRI (O'Craven & Kanisher, 2000) and TMS (Kosslyn et al., 1999), which test the neural basis of imagery in humans objectively (Kosslyn, Ganis & Thompson, 2001a). In sum, as Behrmann (2000, p. 51) points out, when subjects perform visual mental imagery, primary and secondary visual areas of the occipital lobe, such as areas 17 and 18, known as areas V1 and V2, respectively, are activated. Accordingly, as the author describes, when we perceive a visual stimulus, the information is received via the retina of the eye and transmitted through various visual pathways to the brain. The information is then sent to the primary visual area (area 17 or V1) and secondary visual areas (area 18 or V2) before it is sent to the parietal areas of the brain, responsible for representing and coding the spatial information of the stimulus. Also, areas responsible for motion perception of a visual stimulus (Goebel, Khorram-Sefat, Muckli, Hacker & Singer 1998), the colour perception of a stimulus (Howard et al., 1998) and face and place recognition (O'Craven & Kanisher, 2000) are also activated during visual mental imagery. This suggests, as Behrmann (2000) claims, the evidence of shared mechanisms involved in perception and visual mental imagery both at low level (visual areas of the Occipital lobe, such as areas 17 and 18) and high level (visual areas of the Temporal and Parietal lobes) of the visual processing pathways (Felleman & Van Essen, 1991).

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[9] Very importantly, these are *information* about the images, not the images per se. As Kosslyn (2005) points out, images are not stored in long-term memory. Rather, images are created in the visual buffer by activating the stored memories in the format of analog and amodal symbols in the long-term memory.

Apart from the findings elucidated above, that visual mental imagery shares common neural substrates as visual perception (Kosslyn, 1975, 1980, 1981; Behrmann, 2000), and in line with the suggestion that imagery maintains spatial properties and other key features of a visually perceived image due to the involvement of the visual system during imagery tasks, findings from Cognitive Psychology reinforce the hypothesis that features of representation and the way of processing the representation in imagery and in visual perception are equivalent (Iachini, 2011).

More specifically, two classic experiments have investigated whether imagery has some of the same properties as visual perception. For instance, Kosslyn, Ball & Reizer (1978) carried out an experiment in which subjects studied a map of a fictional island containing seven landmarks such as a hut, a tree, a rock, a well, a lake, sand and grass, separated by different distances, and learned to generate accurate images of the map (figure 1.2). In a test phase, subjects were then asked to mentally scan the map and ask questions about the distances between the locations of the hut, the tree and the other landmarks depicted in the map. As a result, Kosslyn et al. (1978) observed a linear relationship between the distances of the landmarks that were mentally compared and the RTs provided by the participants. In sum, more time was required to scan further distances between the landmarks compared to shorter distances, meaning that mental images seem to reflect the spatial properties of observed pictures. Since spatial relations between the observed picture and the mental image seem to be preserved, this result was interpreted as an evidence for the analog/pictorial representation of mental images.

In line with this mental scanning experiment, Shepard and Metzler (1971) presented participants with pairs of 3D cubes (Figure **1.3**), presented at different degrees of inclination, in which the cubes could be either the same shape or mirror images. After exposure to the stimuli, participants had to quickly judge whether the two pictures were the same shape or mirror images by pulling a lever[10]. As reported by Shepard and Metzler (1971, p.701) "to make the required comparison, participants first had imagined one object as rotated into the same orientation as the other (...)". In other words, participants made a *mental rotation* (MR) of the depicted cubes in order to judge whether they were the same shape or mirror images. As a result, Shepard and Metzler (1971) observed that the time required to do the judgment task linearly increased as a function of the angular difference between the two objects. In sum, this cubes are transformed in mental images that seem to move along continuous trajectories as they are transformed, in which, as observed in Shepard and Metzler's (1971), larger transformations demand more time. In order to carry out these image transformations, as Shepard and Judd (1976) point out, subjects employ similar visual mechanisms as in apparent motion of objects (e.g. an optical illusion that makes a still object appear to move) in which they mentally simulate that the cubes are being rotated (Wexler, Kosslyn & Berthoz 2018). Additionally, depending on the strategy employed by the subject in order to mentally rotate the cube to provide an answer, as Kosslyn, Thompson,

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[10] As part of the procedure of these mental rotation tasks, participants are encouraged to remain still and are usually asked not to move any other part of their bodies apart from the hand to pull the lever.

Wraga & Alpert (2001b) point out, in order to carry out a MR of these images, subjects may also make them turn through a motor simulation of the object.

Figure 1.2: Fictional map depicting 7 distinct landmarks used in Kosslyn et al's (1978) experiment (Retrieved from Kosslyn et al., 1978)

As Tomas (1997) points out, one major empirical challenge to the quasi-pictorial account of mental imagery is that both mental scanning and MR can be performed by congenitally blind individuals (e.g. Marmor & Zaback, 1976; Iachini & Ruggiero, 2010). In order to carry out these tasks, congenitally blind individuals typically use haptic exploration through a coordination between tactile, proprioception and motor control (Kerr, 1983; Tomas, 1997), and most studies with this population show that, although RTs are usually slower than sighted individuals', the pattern of results is similar to both groups (e.g. linear increase of RTs as a function of angle disparity in MR tasks) (Carpenter & Eisenberg, 1978). The exploratory physical movements using the sense of touch employed by congenitally blind individuals while carrying out these tasks and the similar patterns compared to sighted individuals reported in these studies suggest that congenitally blind individuals maintain the spatial representations that are present in mental images that sighted individuals use to carry out tasks that involve visual mental imagery, however, this spatial representation arises from a different modality rather than the visual. As the empirical results show similar patterns of response, this mental spatial representation of congenitally blind individuals is functionally similar to sighted individuals' (Kerr, 1983; Farah, Hammond, Levine & Calvanio, 1988; Iachini & Ruggiero, 2010). Finally, as an implication to the theories of imagery, it seems that some aspects of imagery are shaped by the nature of sensory experience that may be evoked by multiple modalities, in this particular case of congenitally blind individuals, through the tactile exploration of the stimuli in order to carry out the

MR and mental scanning tasks (Kerr, 1983; Arditi, Holtzman & Kosslyn, 1988; Iachini & Ruggiero, 2010; Gibbs, 2006).

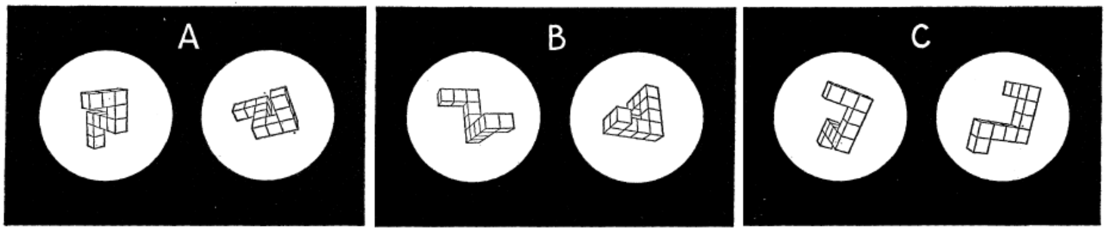

Figure 1.3: Examples of drawings of cubes presented to subjects in Shepard and Metzler's (1971) experiment. Picture A) depicts the same pair of cubes displayed in 80º of inclination in the picture plane. Picture B) shows the same pair of cubes displayed in 80º of inclination in depth. Picture C) shows a different pair of cubes. (Retrieved from Shepard and Metzler, 1971).

Also, as Kosslyn et al. (2001a) point out, although parallel deficits in imagery and perception capacities have been observed in brain-damaged patients (e.g. Farah, 1984), it has also been observed that patients who had impaired visual object recognition (agnosia) could still perform mental imagery tasks normally (Behrmann, Winocur & Moscovitch, 1992). Likewise, Farah (1984) reports that, even though brain-damaged patients were able to perceive and recognize visual stimuli, their ability in generating imagery was damaged. Taking these two examples into account, it is suggested that both visual imagery and perception share many neural mechanisms, however, that does not mean that *all* brain areas activated during visual perception are activated during visual mental imagery, and the same principle applies otherwise. Kosslyn et al., (1997) observed that 2/3 of the cortical areas activated either in visual mental imagery or in visual perception are activated in both cases. Thus, as Kosslyn, Thompson & Alpert (2001a) conclude, lesion in one specific area that is involved in visual perception but is not involved in visual mental imagery will likely damage visual perception, but not visual mental imagery, whereas lesion in areas that are involved in both visual perception and mental imagery may damage both functions.

In sum, in line with the findings from Cognitive Neuroscience, if imagery works in terms of re-activation of some of the neural structures that are used in perception in the absence of physical input (e.g. visual or tactile perception, as we have seen in the examples above), then imagery is the case of a modality-specific cognitive process that is grounded in sensorimotor areas, relying on "representations similar to the original sensorimotor experiences" (Iachini, 2011, p.10), being also a case of conceptual embodiment described in the last section, since it seems that visual mental imagery consists of modal simulation of visual (or in the case of congenitally blind individuals, tactile) processing grounded in modality-specific areas of the brain (Barsalou, 2008). However, as Kosslyn (1980) proposes, visual mental imagery may also involve amodal symbols, responsible for abstract information about the image, along with these analog symbols anchored in modality-specific perceptual systems.

2.2 The case of motor imagery

As Gallese and Lakoff (2005) claim, although the same embodied nature observed in visual mental imagery described in the last section is shared with motor imagery, as both occur in the absence of a physical input (Jeannerod, 1994), some of the neural mechanisms employed in motor imagery differ from those of visual mental imagery (Kosslyn et al., 2001a; Jeannerod, 2006).

As Jeannerod (1994, 1995) points out, one aspect that differs motor imagery from visual mental imagery is that, in the former, images are experienced from a first-person perspective (1PP), in which an agent mentally simulates his/her own bodily movements without physically executing them. In this internal perspective, as Holmes and Calmels (2008, p. 435) argue, the "self is the agent of the behavior", in which there is no subjective distance between the self and the imagined experience (Jeannerod, 1995). As an elucidative example, the agent imagines that he/she is lifting Roland Garros' trophy. In the mental image, the agent can visualize his/her own arms lifting the trophy, but cannot visualize his own face, because the image comes from his/her own perspective. This process, as Jeannerod (1994) argues, necessarily involves a kinesthetic[11] representation of the action, in which the agent feels himself/herself lifting Roland Garros' trophy and his/her own body is the force that generates the action.

Conversely, when the agent experiences the image by placing himself/herself in "someone else's shoes", in a beholder or spectator position (Jeannerod, 1994; Holmes and Calmels, 2008; Mendes, 2015), the agent is experiencing the image from a third-person perspective (3PP). In this case, there is a distancing between the self and his/her imagined experience (Jeannerod, 1995). For example, imagining lifting the Roland Garros' trophy through a 3PP would be similar to as if the agent was visualizing himself/herself lifting the trophy on the television. This process involves a spatial representation of the action in which the action is executed by the subject himself/herself outside of his/her own body, hence, it is not considered motor imagery, but visual mental imagery, since it is an external, exogenous force that generates the action over the imagined body (Jeannerod, 1994; Jeannerod, 1995; Iachini, 2011). Through this perspective, then, the agent would be able to visualize the trophy being lifted and all his/her body parts, including the face and other parts of the body the agent cannot visualize under the 1PP. Finally, although some authors (e.g. Collins, Smith & Hale, 1998) consider that the kinesthetic representation of an action can only be observed under the 1PP,

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[11] As Mendes (2015, p.12) points out, the kinesthetic representation consists of the "one's sensations of 'how it feels' to perform an action", which involves the awareness of the position of our bodily parts in space and how we perform our bodily movements (Callow & Watters, 2005). In the example provided, the kinesthetic representation of lifting Roland Garros' trophy would consist in the sensations of how it feels to lift the trophy, such as muscle contractions, the texture of the trophy that is perceived through the touch of the hand, the weight of the object that is felt while it is being lifted, etc.

some authors (e.g. Callow & Hardy, 2004) claim that these kinesthetic representations may also be observed under the 3PP as long as the external agent represented in the image is the agent himself/herself (then, in the example above, according to these authors, imagining themselves lifting the trophy in a 3PP would also involve a kinesthetic representation of the action).

Another difference that can be observed between visual mental imagery and motor imagery is the brain areas involved in both functions (Jeannerod, 1994). Motor imagery may not necessarily involve the activation of some of the neural substrates involved in visual perception and visual mental imagery described in the last section. More specifically, motor imagery can include only the kinesthetic feeling of a particular imagined motion, but not necessarily any visual representation of the motion (Jeannerod, 1995; Stevens, 2005; Iachini & Ruggiero, 2010). One example of the difference in terms of brain areas activated in visual mental imagery and motor imagery can be provided by Parkinson's disease patients. As Dominey, Decety, Broussolle, Chazto & Jeannerod (1995) observed, although motor imagery ability is relatively slower for Parkinson's disease patients due to damages in the motor cortices, the authors did not observe impairment in visual mental imagery abilities.

In line with the differences in terms of brain areas involved in the visual mental imagery and motor imagery elucidated above, Jeannerod (1994) points out that whereas visual mental imagery shares some of the same brain mechanisms as visual perception, a correlate can be established between motor imagery and motor representations of actions, or the "motor physiology", as he refers (p. 4).

The relation between motor imagery and motor execution is part of a broader framework of action representations called m*otor cognition.* As Jeannerod (2006, p. v) defines, motor cognition is "the way actions are thought, planned, intended, organized, perceived, understood, learned, imitated, attributed, or in a word, the way they are represented", in other words, the "covert stages of action" (Jeannerod, 2001). Apart from these stages involved in action representations, as Jeannerod (2001) points out, studies of motor cognition have also investigated other processes related to the covert stages of action, such as the recognition of tools and objects, learning by observation, or understanding other peoples' behavior. The following section will discuss some of the empirical findings regarding motor imagery within the motor cognition framework described above.

2.3 Empirical findings in motor imagery

First, Jeannerod (2001) reports a series of studies in which brain-mapping techniques were employed in order to measure the neuronal activity of cortical areas activated during action execution, intended action, the imagination of an action and even the observation of someone else's action. In sum, the neuronal network that comprises action execution, intended action and the imagination are the Primary Motor Cortex (Porro et al., 1996), the Basal Ganglia and the Putamen (Gerardin et al., 2000), the Inferior Frontal Gyrus (Bifoksi et al., 1999), the Cerebellum (Ryding, Decety, Sjolhom, Stenberg &

Ingvar, 1993; Parsons et al., 1995; and Grafton, Arbib, Fadiga & Rizzolatti, 1996), the Premotor Cortex, the Inferior Lobule and Intraparietal Sulcus in the Parietal Cortex (Decety et al., 1994), areas in the Pre-Frontal cortex, such as the Dorsolateral part, the Cingular Gyrus, and the Ventral and Caudal zone (Frith, Friston, Liddle & Frackowiak 1991; Iacoboni et al., 1999; Decety and Someville, 2007) and the pre and posterior parts of the Supplementary Motor Area (SMA; Roland, Lassen, Lassen & Skinhoj, 1980).

Although these cortical areas have been reported to be activated during different processes underlying motor cognition, namely motor preparation, motor imagery and motor execution, some elucidations should be made. First, the amount of cortical activation in these areas vary in degree, and according to Jeannerod (2001), the Premotor Cortex and the SMA are regarded as the most activated areas when it comes to executing, intending, and imagining motor actions. Also, very importantly, as Roth et al. (1996) point out, although there is a correlation in terms of neuronal activation between both imagined and executed motor actions in these areas mentioned above, the degree of activation is less strong when motor actions are imagined rather than executed, since the degree of cortical activation for imagined motor actions is never more than 30% of the physical execution. Finally, as Dechent, Merboldt & Frahm (2004) point out, the activation of the primary motor cortex seems to be transient during motor imagery tasks, in which the activation lasts only a few seconds of the imaged task, subsequently vanishing.

In most of these studies described above, subjects had their neuronal activity mapped while either executing an action with the body (e.g. contracting their biceps) and imagining the same action. Alternatively, these studies have also been replicated in cognitive tasks such as MR tasks of bodily-related pictures, in which participants observed body parts on a screen (hands, feet, head or the whole body) and had to either make a laterality judgment of the stimulus or match the pictures onto a target picture. As it will be thoroughly described later in the present study, subjects employ motor imagery techniques while carrying out MR tasks of bodily-related pictures (Parsons, 1994). Neuroimaging studies in MR of hands (Parsons et al. 1995; Kosslyn, DiGirolamo & Thompson, 1998; de Lange, Helmich & Toni 2006; Hamada et al., 2018) observed that brain regions known to participate in the planning and execution of bodily movements were activated. As these authors describe, these areas include the Prefrontal and Insular Premotor areas, the SMA, the Anterior Cingulated, the Superior Premotor Cortex, the Cerebellum and the Basal Ganglia. Since these areas overlap with the areas involved in motor imagery tasks, Hamada et al. (2018, p. 1597) suggest that “when performing MR, subjects at least use partly the same strategy as when performing motor imagery”.

These findings, in part, extend to MR of pictures of objects. In this case, Kosslyn et al. (1998, 2001a) observed that the activation of cortical areas that overlap with those involved in motor imagery varied according to the strategy used by subjects to mentally rotate pictures of multi armed-like objects. Subjects were instructed to either imagine the rotation being done by exogenous forces (e.g. by an electric motor) or by an endogenous force (e.g. as if they were physically turning the object depicted in the picture). Through a PET scan, Kosslyn et al., (1998, 2001b) observed activation in the motor regions of the brain when subjects employed the endogenous strategy to mentally rotate the object in the picture, but not when they imagined this rotation being done by an exogenous force.

Apart from the study of actions executed by the agent him/herself, motor cognition also comprises the observation of other people's actions. In this regard, much work has been devoted to explaining how action observation of other people can influence our own actions (e.g. Rizolatti and Craighero, 2004). First, Di Pellegrino, Fadiga, Fogassi, Gallese & Rizzolatti (1992) and Gallese, Fadiga, Fogassi & Rizzolatti (1996) reported a series of studies with macaques in which it was observed a circuit of neurons in the rostral part of the inferior premotor cortex (area F5) that fired both when the animals physically executed an action and when they observed another animal executing the same action. These neurons are called *mirror neurons*, and are bimodal due to their visual and motor properties – these neurons are activated when the macaques *see* other macaques *physically executing* the same action they had just executed, hence, these neurons possess both visual and motor properties (Rizzolatti, Fogassi & Gallese, 2001). As Rizzolatti and Craighero (2004) and Decety and Sommerville (2007) claim, mirror neurons are important for understanding the actions and the consequences of other people's actions, and for learning new motor skills and motor knowledge by imitation. Finally, Gallese and Goldman (1998) claim that the same mechanisms involved in observing others' actions are the same mechanisms that are activated when we imagine or intend to execute a physical action. In terms of brain areas activated in action observation, imagined and intended actions, it was observed significant activation in the precentral motor cortex (Hari et al., 1998), cerebellum (Grafton et al., 1996), and the SMA (Stephan et al., 1995).

Concomitantly, it was also found out that motor imagery has an effect on the autonomous nervous system and on the physiological bases that are also observed in action execution. Accordingly, when asking subjects to only imagine bending their arms not to execute the physical action, Jacobson (1932) observed movement-relevant electrical activity of the target muscles through an electromyography (EMG). Likewise, also through EMG recordings, Shaw (1940) observed a linear increase in the activation of forearm muscles as a function of imagined weight lifting of different weights (e.g. higher activation of forearm muscles when subjects imagined lifting heavy weights). Oishi, Kimura, Yasukawa, Yoneda & Maeshima (1994) recorded several activities of autonomic effectors simultaneously, such as heart rate (HR), skin conductance response (SCR) and respiration rate (RSR) while subjects performed motor imagery of a speed skate sprint. Compared to rest, HR, SCR and RSR were increased by 57%, 51% and 76%, respectively.

Behavioral findings have also reported the relation between the time and effort needed to perform the same action both mentally and physically. For instance, Decety and Michael (1989) found out that the time that subjects used to write their own signature was the same when they carried out this action both physically or mentally; the same isochrony principle was found when subjects executed or imagined walking the same distances, namely 5, 10 or 15 meters, in which the blindfolded subjects were asked to either walk or imagine walking these distances. As a result, walking times increased as a function of the distance covered (more time to cover 15 meters than 10 and 5, respectively). In the imagined condition, the same pattern was observed, in which the times in imagining walking the distances were found to be similar to its physical counterpart.

It has been argued, though, that this isochrony principle between the imagined and the physically executed action is due to the tacit knowledge that subjects would have when they walked for longer distances – if the distance is longer, the duration of the action should increase, and subjects would consequently report increase of times in the imagined condition as a function of their tacit knowledge of the differences between the walking distances (e.g. Pylyshyn, 1973). Thus, under this tacit knowledge account of the isochrony principle between the imagined and physical action, in the imagery condition, participants would be simply replicating the temporal sequence they had registered when they physically walked the distances (Jeannerod, 1994). However, as Jeannerod (1994) argues, if duration of a mentally imagined action is a function of muscular force and other variables, then it is hypothesized that duration times between the imagined and actual physically executed action should differ when subjects physically walk a distance with or without a load, since the load would not affect the imagined condition, only the physical execution of the action. This hypothesis had been investigated by Decety, Jeannerod & Prablanc (1989), in which participants had to physically and imagine walking a given distance with and without a 25kg backpack. In the physical condition, participants were asked to keep the same speed as when they walked with or without the backpack; hence, whenever they had to physically walk with the backpack, they had to employ greater force in order to carry out the physical task in the same time as they carried out the task without the 25kg load. As a result of the imagining task, it was found out that duration of imagined walking with a 25kg was 30% superior to the imagined walking without the load, even though the time spent to physically execute the task was the same for both conditions. As Jeannerod (1994) suggests, subjects were not just replicating the estimation of duration times they had experienced when they physically walked the distances, but that the force applied while subjects carried the 25kg backpack must have been used as a cue so they could evaluate the movement duration in the imagined condition.

Apart from the isochrony principle between motor imagery and motor execution, motor imagery also seems to share the same kinematic principles (properties of executed movements) as motor execution. In other words, it has been observed that motor rules and biomechanical constraints of the body also characterize the properties of motor images. For instance, Johnson (2000) presented a dowel in distinct orientations in front of subjects that had to verbally indicate which grip posture (overhand or underhand) they would employ in order to grasp the dowel and move it away. As a result, Johnson (2000) observed that the time subjects spent in order to give a response regarding the grip posture they would use to execute the task linearly increased as a function of the angular distance the subjects' hand would have to cover in order to grasp the dowel in the most comfortable hand position, avoiding biomechanically awkward trajectories. Likewise, Frak, Paulignan & Jeannerod (2001) found that subjects' judgment about the feasibility in grasping a cup of tea (in this case, to say whether grasping the cup would be easy or difficult) linearly varied according to the orientation of the cup's handle, in which subjects provided a faster response when the cup was in a orientation in which we are accustomed to physically grasp than when the cup was in another orientation. Taken together the results of these two studies described above, Jeannerod (2006) supposes that subjects employed implicit motor imagery used on a daily basis when they perform these actions (e.g. physically grasping a cup of tea), and consequently, the results resemble the biomechanical constraints of the body.

Much work examining the functional effects of motor imagery on motor execution through mental training has been carried out in some other fields, such as sports psychology, music learning, physiotherapy, etc. Amongst the many findings in sports psychology, for instance, Murphy, Nordin & Cumming (2008) observed that groups of professional golfers who underwent a three-week program of motor imagery and physical practice combined had better performance improvement in bunker shots compared to those groups assigned only to the physical practice of the movements, and did not perform any motor imagery of the task. Likewise, mental rehearsal and physical practice of a musical piece led to superior performance for guitarists compared to physical practice alone (Theiler & Lippman, 1995). Finally, Liu, Chan, Lee & Hui-Chan (2004) observed that the relearning of movements of daily tasks (e.g. putting the clothes on hanger and fold the laundry) in stroke patients assigned to mental practice of activities of daily living plus physiotherapeutic treatment was significantly better than subjects who received the conventional treatment only.

As an explanation for these three findings regarding the functional effects of motor imagery on the physical execution of actions, on Jeannerod's (2006) account, by mentally rehearsing a physical action, the activation of the motor system may facilitate future execution of the action. Jeannerod's (2006) hypothesis is supported by experimental data. For instance, by mapping the motor cortical area using a TMS when subjects learned a five-finger exercise on the piano, in which some were assigned to the physical practice and some to the mental training group, Pascual-Leone et al. (1995) observed that the levels of excitability of the motor cortex of subjects assigned to the mental training group increased the same way over the five days of training as compared to subjects assigned to the physical practice group.

Given the empirical findings described above, according to Jeannerod (1995, p. 1419) "motor images are endowed with the same properties of those of the corresponding motor representations, and therefore have the same functional relationship to the imagined or represented movement and the same causal role in the generation of this movement". This claim raised by Jeannerod (1995) is regarded as the *functional equivalence hypothesis* between motor imagery, motor preparation and motor execution

(Jeannerod, 1994). In the light of the functional equivalence hypothesis raised by Jeannerod (1994), the next section will thoroughly discuss the motor representations that underlie motor imagery and motor preparation of one's own actions, and the relationship between these two instances of motor representations.

2.4 Motor imagery and motor preparation of one's own actions

The findings described in the last section about the brain mechanisms, the physiological correlates and the relationship between time and force in the imagery of physically executed movements have raised questions regarding the nature of motor representations of actions. In line with these findings, Jeannerod (1994, p. 193) hypothesizes that motor representations for acting and imagining are one of the same thing, underlying a "continuum between motor preparation and motor imagery", which contrasts to "classical ideas of a unitary symbolic representation for the different types of mental activities, including motor representation".

As observed in section 2.1 of this present study, the account that mental images can be expressed by language-like amodal, abstract symbols in an unitary representational system, has been confronted by, for instance, the view proposed by Paivio's (1971/1986) with his dual coding theory, and by Kosslyn's (1980) analog theory for visual mental imagery. In line with Paivio's (1971/1986) dual coding theory, Jeannerod (1995) claims that although the linguistic and the imagery systems are functionally independent but still interconnected, motor images are difficult to describe verbally (e.g. the details of the motion of the leg when a footballer kicks the ball towards the back of the net), unlike visual images and the features of the represented object (e.g. shape, size, color, etc.). Yet, motor representations, as Jeannerod (1994, 1995) claims, are cognitively accessible through the behavioral paradigms reported in the previous section (e.g. the matching and the chronometric measure between a physically executed movement and its imagined counterpart).

Although Jeannerod (1994) claims that motor representations of actions underlie a continuum of motor preparation and motor imagery that encode the properties of physically executed action (e.g. time similarity, effort, biomechanical constraints of the body, etc.) and some of the same neural structures are shared by both, the author points out that both differ in terms of nature (or, as we will see, in terms of degree). On the one hand, motor preparation has an implicit nature, being a non-conscious process that cannot be accessed by the subject's awareness, in which only the final result (the action) can be consciously accessed by the subject. On the other hand, motor imagery and the content of motor images can be consciously accessed by the subject.

This difference between motor preparation and motor imagery is further described by Jeannerod (1994, 1995, 2006). First, motor representations, as Jeannerod (1995, p.1427) points out, are defined as "internal models of the goal of an action, (in which) the goal of an action can be specified at different levels which represent different aspects of the same action". In other words, as Jeannerod (2006) claims, actions have goals and most of the times we are aware of the goal to be reached and the subsequent action that needs to be undertaken in order to accomplish the goal. However, this does not mean that we are aware more specifically of *how* to reach that goal. For instance, when people start to walk voluntarily, the intention of that movement is toward a goal (e.g. arriving at a certain place) and not the way the legs are moving. Moving the legs in order to accomplish the goal (arriving at a certain place) seems to be, in this case, an automatic set of movements. Most of our actions are prepared an executed this way, directed at an external object and goal-oriented. Jeannerod (2006, p. 46) hypothesizes that this automaticity that underlies most of our actions is a "prerequisite for their accuracy". In fact, the motor preparation of one's action should have a short life-span, since most of the times one action is followed by another action, which is followed by another one, and so on (e.g. in order to walk to reach a certain destination, the movement of one leg is usually followed by the movement of the other leg, resulting in a motion towards the front). Thus, physically executing a set of movements fast and accurately involves a time constraint, which leaves no space for consciousness to appear every time we carry out an automatic action. For example, when people learn to execute a new motor skill (e.g. a child learning how to swim on a butterfly mode), the movements are usually executed under conscious control, in this case, the child has to move his/her arms and legs very slowly and probably inaccurately in order to learn the movements of his/her arms and legs to execute the swimming on butterfly mode properly. After training, these movements that once were under conscious control become automatic and executed faster and more accurately. In sum, Jeannerod (2006) argues that consciousness arrive too late when we execute automatic goal-directed actions, hence, it should not play a causal role in this stage of planning or organizing the physical execution of automatic goal-directed actions.

Further, Jeannerod (1994, 1995) claims that there is a fine line between motor preparation (non-conscious) and motor imagery (conscious) along the continuum of motor representations that he proposes. More specifically, when motor preparation, which, according to the last paragraph, usually has a short life-span in automatic goal-directed actions (Jeannerod, 2006), is prolonged, the intention to act would become "a motor image of the same action" (Jeannerod, 1994, p. 193). Likewise, when an action is planned and purposely blocked at the last moment, it could also be transformed in a conscious mental image. As Jeannerod (1995) claims, in these conditions where action is prolonged in the motor preparation stage, or is blocked and not physically executed, the motor memories are not erased completely and neurons fired during the motor preparation phase remain activated. These motor memories and the neural activation of the motor action after the fail/block in execution would then give rise to conscious motor images. The hypothesis that motor images could be originated after fail/block of physical execution of an action or due to a delay in the motor preparation stage, are supported by studies with amputated subjects (e.g. Schilder, 1935). In these cases, subjects report as if they were feeling movements in the phantom limbs and also report having a clear image of the movement that was not executed, suggesting that purposely blocked execution of the action does not cancel the representation of the action in the cases of amputated subjects, hence, the representation of the action remains accessible to conscious processing (Jeannerod, 1994).

In sum, as Decety and Grèzes (2006) point out, both conscious (motor images) and unconscious (motor preparation) levels are not independent from each other, but rather they represent different aspects (that vary in terms of degree) of a continuum inserted within the motor cognition framework when it comes to the simulation of motor actions. In the following section, this continuum that comprises motor preparation, motor image and motor execution and how are they related to each other in motor simulation will be discussed. Also, the relation between motor simulation and weak conceptual embodiment will be established.

2.5 Motor simulation

In the light of the empirical findings described in section 2.3 and the functional equivalence hypothesis between motor imagery, motor preparation and motor execution proposed by Jeannerod (1994), a theory of motor simulation has been proposed.

According to Jeannerod (2001) this motor simulation system relies on the motor system, involving a network of covert aspects of the action (e.g. motor preparation and motor imagery) and the physical execution of the same actions, the overt aspect. As the author hypothesizes, “this simulation network is activated under a variety of conditions that relates to action, either self-intended or observed from other individual. (…) the function of this process of simulation would be not only to shape the motor system in anticipation to execution, but also to provide the self with information on the feasibility and the meaning of potential actions” (p. 104). Moreover, as Jeannerod (2006) points out, this simulation process requires the activation of the motor system. This hypothesis raised by Jeannerod (2001) on how this simulation network would actually work and the conditions in which it is activated will be clarified in the following paragraphs.

First, it is important to note that this simulation theory comprises not only the actions that we perform ourselves, but also the perception of other people’s actions. Although the scope of the present study is to discuss the accounts of simulation and motor representations of our own actions in the light of weak conceptual embodiment and the ECT, it is noteworthy to briefly refer to the simulation present in action observation since both types of simulation may recruit some of the same neural structures, but may differ in some aspects, and because simulation of other people’s actions allows us to acquire motor knowledge that will guide our own actions in the future (Decety & Sommerville, 2007).

As observed in the section about the empirical findings in motor imagery, it has been found out that macaques possess mirror neurons, which are activated when they see other macaques physically performing the same action they had just executed (Di Pellegrino et al.,1992; Gallese et al.,1996; Rizzolatti et al., 2001). Likewise, humans' Precentral Motor Cortex (Hari et al., 1998), Cerebellum (Grafton et al., 1998), and the SMA (Stephan et al., 1995) are reportedly implicated when we observe other people physically executing an action. These brain areas, as we have seen in section 2.3, are part of the mechanisms involved in the motor cognition framework, which comprises motor imagery, motor preparation and motor execution. Hence, observation of others' action shares the same representational system as motor imagery, motor preparation and motor execution (Decety and Sommerville, 2007).

When we observe and simulate other people's actions, Gallese and Goldman (1998) argue that, to some extent, we represent their actions much the same way we represent our own. As the authors claim, "when one is observing the action of another, one undergoes a neural event that is qualitatively the same as the event that triggers actual movement in the observed agent" (p. 498). Moreover, the covert simulation and representation of other people's action may provide us with insights into the plans, beliefs and desires that motivate other individuals to perform a particular action, and by doing this we understand the action performed by other people, why that action was performed, predict the future behavior of that individual, the consequences of that action, and learn how to replicate the action in the future ourselves (Rizzolatti, Fadiga, Fogassi & Gallese, 1996; Jeannerod, 2001; Decety and Sommerville, 2007).

Jeannerod (1994) provides a very interesting example of learning through observation-based simulation: a student learning how to play a music instrument (e.g. the piano) observes the teacher playing the piano; the student is instructed to later imitate the teacher and play the instrument just like demonstrated. Although the student had just observed the teacher playing the piano, he must imagine in his mind the teacher's action (in this case, the way he strikes the piano keys). When they change role and the student is on the piano replicating the teacher's movements that had just been observed, the teacher observes him playing and, despite he is not playing the piano himself, he understands the student's action (the way the student plays the piano) and may experience a feeling of how the piano should be played. Then, based on this feeling and on his observation, he may provide the student with some feedback on how to improve his piano playing skills. In sum, Jeannerod (1994) speculates that this imitation-based learning technique is based on the discharge of mirror neurons as both teacher and student observed each other playing the piano.

Although there is evidence that action observation shares the same representational system as our own actions, the simulation of other people's actions may differ from simulation (or some stages of simulation) of one's own actions. The main difference, as Iachini (2011, p.16) claims, is that motor imagery "is a simulation processes generated internally, voluntarily, and requires conscious control", whereas the action observation is "generated by en external event, is automatic, and does not require conscious control". Also, action observation is an online process, which occurs in the presence of the stimulus – in this case, the action being observed. On the other hand, motor imagery is the case of an offline process that utilize perceptual and motor systems, in which the physical input is not currently present (Hostetter & Alibali, 2008; Borghi, 2011).

In the case of self-intended actions, Jeannerod (2001) argues that covert actions (e.g. mentally prepared or mentally imagined) are *actually actions*, except for the fact that they are *not overtly executed*. As the author claims, the two stages – the overt and covert stage of actions – are part of a continuum in which every physically executed action necessarily has a covert stage. However, not every covert stage of an action turns out to be physically executed. This covert stage, as Jeannerod (1999) points out, can be seen as a pragmatic representation of the action, which includes the goal of the subsequent action, the means to achieve it and the consequences of the action. As reported in the empirical findings of motor imagery section, motor representations of an action also include time and effort to perform an action, and the motor rules and biomechanical constraints of our body. Finally, as described in the last section, the covert stage of an action consists of motor preparation and motor imagery. Although we can consciously generate images of our own actions, the process involved in generating an action takes place at a more unconscious level in the motor preparation stage (Decety & Grèzes, 2006).

MR of bodily-related pictures seems to be an example of "covert simulation of motor rotation" (Wexler et al., 1998, p. 78). As described in the empirical findings of motor imagery section, when subjects carry out a MR of bodily-related pictures, they seem to rely upon cortical areas that overlap with those involved in motor imagery. Likewise, it has also been reported that, in order to accomplish the MR of bodily-related pictures, subjects take their own bodies as a reference, thus imagining as if they were physically rotating their own limbs or other parts of the body. By employing this strategy, it was observed a correlation between the time to mentally rotate a picture of a hand and to perform its overt counterpart, since RTs of pictures depicted in larger degrees of inclination were much higher compared to pictures displayed in the canonical orientation, those that actually resembled the canonical position of our limbs and our body in space (Parsons, 1987a, 1987b, 1994). Thus, as Wexler et al. (1998) point out, when we carry out a MR of bodily-related pictures, we usually plan to rotate our own limbs in order to guide us to a response to the stimulus displayed on the screen, but we do not physically execute this action (by default, before a MR task, either of cubes or bodily-related pictures, subjects are instructed not to move their body while they perform the task). Apart from consisting of simulation of bodily movements in a 1PP, MR of bodily-related pictures seem to be an example of a task in which the structural features of one's body play a constraining role in the performance. This correlation between performance at MR of bodily-related pictures and the claim from ECT that the body plays a constraining role in cognition will be further explored in the following section of the present study.

Apart from MR of bodily-related pictures, this simulation of an overt action seems to take place when subjects also carry out MR of inanimate objects. In this case, however, subjects only simulate the action of rotating an object when they carry out the task in which the endogenous force referred in the empirical findings of motor imagery is responsible for the MR of the object (e.g. grasping a cube and rotating it until the subject is able to provide a response). On the other hand, if an exogenous force is responsible for the rotation of the object, subjects do not perform the task imagining as a simulation of their hands rotating the object, but rather, by an external force doing it (e.g. an electric motor) (Kosslyn et al., 1998, 2001b).

Jeannerod (2001) provides two hypotheses of why the activation of the motor system does not result in overt movements. First, it is claimed that the activation of the motor system during simulation is *subliminal*, therefore, not sufficient to cause the discharge of spinal motoneurons. This hypothesis is consistent with the findings by Roth et al. (1996) and Dechent et al. (2004). Whereas the former observed that, by comparing cortical activation in the primary motor cortex, the activation elicited by motor imagery corresponded to 30% of the total sum of activation of overtly executed tasks, the latter reported that the activation of the primary motor cortex lasted only a few seconds, promptly vanishing. As an alternative explanation, Jeannerod (2001) proposes that motor execution is blocked before the motor preparation stage of an action reaches the *motoneuron* level, in which an inhibitory mechanism would be generated simultaneously to the motor activation. On this account, Jeannerod and Frak (1999) suggest that the inferior Frontal Cortex is the area responsible for motor inhibition during motor simulation. The authors made this suggestion based on Deiber et al's (1998) study that used a PET scan to observe the activation in cortical areas when subjects both imagined or imagined and physically executed finger movements. As a result, in the latter condition, the authors found an activation decrease in the inferior prefrontal cortex in comparison to the former condition.

Brain lesions in the motor areas have been reported to affect the functioning of this simulation network proposed by Jeannerod (2001) as studies with patients that suffered from brain lesions in specific brain areas have demonstrated that the patients were unable to mentally perform physical actions. This has been observed in hemiplegic patients who suffered corticospinal lesions, in which one hand was affected by the brain lesion and the other was not. As Sirigu et al. (1995) observed, motor imagery was slower for the affected limb compared to the non-affected one. Likewise, Parkinson's disease patients who suffered from lesions in the Basal Ganglia showed the same asymmetrical pattern of performance in terms of motor imagery tasks involving their hands (Dominey et al. 1995). Apart from these studies indicating an asymmetrical pattern of responses in terms of motor imagery tasks of hand movements, impairments that result from Apraxia syndrome also affect motor representations of the patient. In this case, as Sirigu et al. (1996) observed, these patients fail to distinguish their own actions from actions performed by other people. Finally, patients with lesions in the Prefrontal Cortex, more specifically, in the Orbitofrontal areas (Shallice, Burgess, Schon & Baxter, 1989) compulsively imitate actions performed by another person in front of them and cannot refrain from grasping objects. Although there are still no studies that investigated if this sort of lesion impaired motor imagery in these patients, Jeannerod (2001) supposes that, due to their compulsion in imitating other people and grasping objects, these patients would probably immediately transfer their motor images into a motor output.

In summary, the simulation theory proposed by Jeannerod (2001) predicts that the covert stage of a given action is the action itself; however, the covert action has either subliminal neural activation or is blocked at some point, not being physically executed. In line with this claim, it has been found that both covert and overt actions are part of a continuum in which some of the same neural mechanisms are used when we plan, imagine or execute an action. These neural substrates are typically located in the Premotor and Motor cortices, as observed in empirical findings of motor imagery; hence, this simulation process occurs in modality-specific systems and makes use of the re-activation of neural circuitry that is also active in bodily perception, motor action and introspection. In other words, in line with this framework that comprises motor cognition and conceptual embodiment discussed in section 2.2 of the present study, since concepts deploy the simulations of perceptual, motor and introspective experiences, then motor concepts deployed in motor imagery seem to be grounded in modality-specific systems of the brain, namely, the motor cortices; thus, if Jeannerod’s (2001) simulation theory is correct, then motor simulations would make the case for weak conceptual embodiment, in which some concepts (in this case, motor concepts deployed in motor imagery) are grounded in modality-specific areas, such as the motor cortices (Barsalou, 1999; Svensson & Ziemke, 2004; Decety & Grèzes, 2006). The next section will provide examples of how the non-neural parts of the body can play a constraining role in cognitive processes, in particular, in motor imagery.

2.6 Body as a constraint on motor imagery

As described in the introductory notes and in section 1.2.1 of the present study, one of the central tenets of the ECT is that the specific body we have intrinsically *constrains* the nature of mental activity, shaping the cognitive activity and the content of our mental representations, according to Foglia and Wilson (2013). More precisely, Wilson and Foglia (2017, p. 7) raise two possible implications that the claim that the body constrains cognitive activity may have:

1) “Some forms of cognition will be easier, and will come more naturally, because of an agent’s bodily characteristics; likewise, some kinds of cognition will be difficult or even impossible because of the body that a cognitive agent has.
2) Cognitive variation is sometimes explained by an appeal to bodily variation”

In line with the two implications derived from the claim that our specific body constrains the nature of cognitive processing pointed out by Wilson and Foglia (2017) above, this section will describe some theoretical assumptions and empirical findings of the human body functioning as a constraint on motor imagery, in special, in cognitive tasks such as MR of bodily-related pictures.

First, the claim that the body can play a constraining role in cognition has been studied in a wide range of cognitive activities other such as memory (e.g. Dijkstra, Kaschak & Zwaan, 2007), language comprehension (e.g. Glenberg & Kaschak, 2002), valence of stimuli (e.g. Foroni and Sermin, 2009), decision-making (e.g. Casasanto, 2009), etc. Apart from these cognitive activities, the 'body as a constraint' on cognition can also be observed in studies related to motor imagery. Since motor imagery consists of a simulation of overt movements, cognitive tasks that require motor simulation may take into account the biomechanical aspects of the body (Jeannerod, 1994, 1995, 2001, 2006).

As observed in empirical findings of motor imagery of the present study, the time to either respond about the grip posture that would be the most comfortable to grasp and object and the judgment about the feasibility in grasping a cup of tea linearly increased as a function of the position in which the object was displayed on a screen and the biomechanical constraint and the motor rules of the human body (Tucker & Ellis, 1998; Johnson, 2000; Frak et al., 2001). Similarly, when subjects observed rapidly alternating photographs of the human body in different positions, depicting an apparent motion, Shiffrar and Freyd (1990) reported that paths of apparent motion take into account the biomechanical constraints of our joints. Finally, when examining the identification of human actions and body postures in long-term priming experiments with static pictures of a human model, in which subjects had to either describe the pose or judge whether the target picture depicted a possible or impossible human pose, Daems and Verfaillie (1999) observed no long-term facilitating priming effects in case of pictures depicting impossible human poses compared to pictures depicting anatomically possible human poses (Amorim, Isableu & Jarraya, 2006).

Perhaps one the most studied experimental tasks that can exemplify the 'body as a constraint' on motor imagery is the MR tasks of bodily-related pictures. According to Wexler et al. (1998), instead of physically executing a rotation with the hand or other body parts, in MR tasks we plan the action but do not physically execute it. As it is proposed by some authors (e.g. Wohlschläger, 1996; Wexler et al., 1998, Kosslyn et al., 2001a;), rather than being a perceptual phenomenon only, MR of bodily-related pictures is also supposed to be an imagined action in the sense that its only difference to motor action is the absence of motor output.

In line with this link between covert action and MR tasks of bodily-related parts, as Cooper and Shepard (1975) point out, people find it easier to mentally rotate body parts in ways that would be less awkward to rotate them physically. In this case, it is important to note that the awkwardness in the overt execution of a movement referred by Cooper and Shepard (1975) is directly correlated to the angle in which the picture of (in this case) the body part, or the whole body, displayed on the screen. As it has been reported in several studies, the time to make a laterality judgment of a stimulus reflects the degree of MR needed to bring one's body parts to a position adequate for achieving the task, reflecting on an almost perfect linear increase of RTs with angular stimulus disparity (Parsons, 1987a; Parsons, 1987b, Parsons, 1994; Parsons et al., 1995; Wolschlager, 1996; Parsons & Fox, 1998). Thus, as Wexler et al. (1998) point out, in the case of the rotation of one's hand, the angle in which the picture is displayed on the screen would limit the biomechanics of the arm joints when one physically rotates the hand, hence, RTs and ACC levels in MR tasks of bodily-related pictures reflect the biomechanical constraints of the body. The same patterns of RTs and ACC levels have been reported in MR of pictures of feet and the whole body, in which the limbs are outstretched in different orientations (Parsons, 1987a; Parsons, 1987b). In sum, in line with one of the central claims from ECT, more specifically, that an organism's bodily structures play a constraining role in cognition, since subjects employ simulations of their own bodily movements to accomplish the MR of bodily-related pictures, and performance decrease according to the awkwardness of the position of the body part displayed on the screen that ultimately reflects on subjects' biomechanical constraints, then MR of bodily-related pictures could be the case of a task in which one's bodily structures play a constraining role cognition, and consequently, in performance (Parsons, 1987a 1987b, 1994, De Lange, Helmich & Toni, 2006).

As stated in the simulation section of the present study, Kosslyn et al. (1998, 2001b) reported that motor imagery strategies can be applied in the MR of objects, provided that subjects simulate the rotation of the object with their own hands. When rotating the object through an endogenous force, Kosslyn (2001b) observed very similar RTs patterns as those observed in studies of MR tasks of bodily-related picture: a linear increase of RTs and decrease in ACC levels according to the angle of inclination of the object, suggesting that biomechanical constraints of the body may also play a role in MR of inanimate objects when endogenous forces are responsible for the MR of the object.

Apart from Kosslyn et al's (1998, 2001b) studies regarding the different strategies employed by subjects in order to carry out a MR of inanimate objects, Amorim et al. (2006) investigated whether providing inanimate objects (e.g. cubes) with bodily characteristics (e.g. by adding head, hands, and feet to the object or displaying the picture of a human pose resembling the shape of the cube) would facilitate the MR process and, consequently, speed up the MR required in order to match distinct shapes to a target. As a result, Amorim et al. (2006) observed that subjects had lower RTs and higher ACC levels when they performed the MR task and, consequently, the picture-matching task of cubes with bodily characteristics or the human poses simulating the cubes compared to ordinary cubes. In line with these results, Amorim et al. (2006) suggest that the added bodily characteristics to the cubes provided *spatial embodiment* to the objects. This spatial embodiment (Lakoff and Johson, 1999) was used to "map one's body axes (head-feet, front-back, left-right) onto the reference posture", in this case, the cubes (Amorim et al., 2006, p. 344), allowing subjects to perform a simulation of the movement by taking their own bodies as a perspective to carry out this simulation, and therefore, the rotation of the objects. This process, as Amorim et al. (2006) claim, facilitated subjects' performance in the MR task by helping maintaining the postural configuration of the object during the task. Finally, this study has also reported that subjects had more difficulty (slower RTs and lower ACC levels) in the MR and picture matching of pictures of the cubes with bodily characteristics depicting biomechanically impossible human poses compared to those that depicted biomechanically possible postures.

In sum, these MR findings elucidated above are consistent with the hypothesis that MR of bodily-related pictures rely on similar mechanisms involved in the continuum of motor preparation, motor imagery and motor execution stated by the functional equivalence hypothesis proposed by Jeannerod (1994, 2006), in which the biomechanical constraints of the body are taken into consideration when subjects perform the simulation of their body parts to carry out the task, limiting the RTs and ACC levels under conditions in which the stimuli depicted on the screen requires biomechanically impossible movements by the subject.

As observed in the simulation section of the present study, brain lesions that affect the modality-specific systems, such as the motor areas (e.g. Parkinson's disease) seem to constrain patients' abilities to perform motor imagery of hands movements (Dominey et al., 1995), as well their abilities to distinguish their own actions from others' (Sirigu et al., 1996) and the possibility of turning every motor imagery task into a motor output (Shallice et al., 1989). In line with these findings, it has been reported that MR abilities are also impaired due to neurological conditions. Fiorio et al. (2007) observed that patients with focal hand dystonia, a neurological disease that causes the loss of control of hand movements and involuntary contractions of the muscle (Elbert et al., 1998), only had their abilities to mentally rotate pictures of hands impaired compared to control subjects; MR of pictures of feet remained unaffected. Likewise, in a study with patients affected by idiopathic cervical dystonia (CD), a neurological condition characterized by the loss of voluntary neck movements, leading to abnormal neck rotations (Jankovic, Leder, Warner & Schwartz, 1991), Fiorio et al. (2007) observed that subjects with CD had impaired MR of bodily-related pictures (heads, hands and feet) compared to control groups; however, this condition only affected this specific modality of MR, since RTs and ACC levels between CD patients and the control group were not significantly different.

It has also been observed that MR of bodily-related pictures abilities is impaired due to peripheral alterations, such as limb amputation. Although the loss of a limb, either dominant or non-dominant, did not impede subjects to perform motor imagery tasks such as MR of bodily-related pictures, Nico et al. (2004) observed that the amputees' group performance was significantly worse than the control group in terms of RTs and ACC levels. Interestingly, both groups had similar response patterns, in which it was found a correlation in terms of RTs and ACC levels of pictures of hands depicted in biomechanically awkward degrees of inclination between the groups. Finally, this impairment in MR of bodily related pictures observed in amputees was strongly affected by the side of the limb loss, in which RTs were slower and ACCs levels were lower for stimulus that depicted amputated dominant limbs than non-dominant counterparts.

As an explanation for these findings, Fiorio et al. (2006, 2007), Moseley (2004) and Nico et al. (2004) argue that limb amputations cause a disruption in a subject's *body schema*. In sum, body schema is a long-term organized unconscious representation of the body and the spatial relationships between body parts and the environment (Reed, 2002; Gallagher, 2005). Moreover, body schema, as Gallagher (2005, p. 24) points out, is a "system of sensorimotor capacities that function without awareness or the necessity of perceptual monitoring" that enables/constrains bodily movements. This system, as Fredericks (1985) and Moseley (2004) claim, is originated from multimodal sensations from visual, tactile, proprioceptive and vestibular inputs and is integrated with our motor system. The body schema, as Reed (2002) argues, provides us with the knowledge about our own body movement constraints and how a body movement can be performed. For instance, poking the nose with the hand requires a coordinated functioning of the knowledge of the movements required to carry out the goal of raising our hand and touching our nose in a not-so gently way, and body schema provides us with the basis for this knowledge.

As Reed (2002) and Fiorio et al. (2007) claim, there is a close link between our body schema and the abilities to perform MR of bodily-related pictures, since this task involves a spatial transformation of our own body parts (Parsons, 1987a). Thus, in line with the results of the abovementioned studies and the link between body schema and the abilities to carry out MR of bodily-related pictures, it is suggested that limb amputations result in a disruption and change in the body schema system, affecting the perception of the limbs depicted on the screen and, consequently, constraining the performance in tasks such as MR of bodily-related pictures (Moseley, 2004; Nico et al., 2004; Fiorio et al., 2007)[12].

3 Music Perception[13]

In line with the topics discussed so far in the present study, a good amount of work within the field of Music Psychology has investigated how music perception engages the motor cortices (Patel & Iversen, 2014). First, studies that employed brain mapping techniques have found out that perception of music and musical features, such as timbre, pitch, rhythm, melody and harmony, are not solely confined in the auditory cortex, but that an interconnected network that comprises sensory, motor, affective and cognitive systems is also involved in music perception (Leman & Maes, 2014; Schaefer, 2014). In particular, it has been discussed the relationship between brain areas that have also been reported to

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[12] Nico et al. (2004) speculate that a functional prosthesis of the limb that reestablishes part of the movements of a normal limb could be incorporated as part of the body schema of subjects, and eventually improve their performance in MR of bodily-related pictures.

[13] A Glossary for some of the musical terminologies used in the sections regarding music perception is presented after the Appendixes of the present dissertation.

underlie motor cognition and how the activation of these areas is elicited when people are exposed to a variety of musical stimuli (Jeannerod, 2006; Grahn & Brett, 2007; Chen, Penhune & Zatorre, 2008a; Chen, Penhune & Zatorre, 2008b; Leow & Grahn, 2014). Furthermore, in line with the suggestion that an interconnected network of sensory, motor, affective and cognitive systems are involved in music perception, the relationship between music and mental imagery has also gained relevance in recent decades, giving rise to several studies that aimed to investigate the direct causal role that music may have over mental imagery and vice-versa (e.g. Quittner & Glueckauf, 1983; Tham, 1994; Rauscher, Shaw & Ky, 1993; Theiler & Lippman, 1995). More prominently, it has been observed that after listening to particular pieces of music, subjects had better performance at mental imagery-related tasks compared to control conditions, such as silence and relaxation instructions. This finding has been labeled as the *Mozart Effect* (Rauscher, Shaw & Ky, 1993), and received much attention in the beginning of the 90's decade, being replicated and discussed in terms of possible brain mechanisms that would underlie the effect or, at times, the validity of these findings. This section aims to thoroughly discuss 1) the brain mechanisms involved in music perception, in special, brain areas that also comprise motor cognition, and 2) the relationship between music and mental imagery.

3.1 Brain mechanisms of music perception

Music is regarded to be part of the human nature (Koelsch, 2010). As Krueger (2013) points out, music is not just an object of mere aesthetic contemplation, but is rather a resource that we can use to do different things, from dancing in a party with friends to mourning at a family member's funeral. Since early civilizations (e.g. Ancient Greece), the effects of music perception on our emotions and on our cognition has received particular attention. For instance, by proposing that musical scale is based on intervals of mathematical rations (e.g. 3:2. 2:1, 5:4, etc.) between notes within an octave, Pythagoras found that some of these intervals fit well together and produced beautiful melodies and consonant harmonies (Bilotta, Pantano & Talarico, 2000), which were seen as "divine revelations of universal harmony" (Miranda, 2002, p. 6). However, instead of being just classified in terms of Pythagorean mathematical ratios between them, Aristoxenus, an Aristotelian philosopher, claimed that musical intervals should also be classified according to the emotional effects they may have on the listener; with Aristoxenus' claim, the need to focus on scientific studies of the effects of the music on the brain had been addressed (Levitin, Grahn & London, 2018). As such, considerable progress has been made to address the effects of the music on the brain since then: Nowadays, twenty centuries later, not only it has been found out that music perception can virtually modulate activity in limbic and paralimbic structures, the core structures of emotional processes (Koelsch, 2010), but it has also been widely reported that perception of music also elicits brain activation in areas that comprise network systems of language, motor control, emotions, and may share some of the functional properties as other perceptual modalities, such as, for instance, vision (e.g. Bodner, Muftuler, Nalcioglu & Shaw, 2001; Zatorre, Chen & Penhune, 2007; Koelsch, 2010, 2011; Leman & Maes, 2014). Some of these findings will be discussed in the next sections.

3.1.1 Brain areas involved in music perception

In his model of neural basis of music perception, Koelsch (2011, p.1) suggests that music perception involves distinct processes, such as "acoustical analysis, auditory memory, auditory scene analysis, processing of interval relations, (analysis) of musical syntax and semantics, and activations of (pre) motor representations of actions". Some of these processes will be discussed below.

First of all, the process of music perception begins with the extraction of acoustic information conveyed by the music. This acoustic information is transduced into neural activity in the cochlea, in which the auditory brainstem will progressively extract information from some of the properties of the sound just heard, such as periodicity, timbre, and intensity (Langner & Ochse, 2006; Koelsch, 2011). Once the acoustic information is transduced into neural activity, the thalamus is responsible for projecting these neural impulses into the Primary Auditory Cortex (PAC), which is located in the Broadmann's area (BA) 42, and two adjacent secondary auditory cortical areas, situated in areas such as BA 42 and BA 52 (Kaas & Hacket, 2000; Koelsch, 2011). These auditory areas, as Koelsch (2011, p. 2) points out, are involved in some more fine-grained analysis of acoustic elements of the music in comparison to the auditory brainstem, such as "auditory sensory memory, extraction of inter sound relationships, discrimination, and organization of sounds as well as sound patterns (e.g. frequency and periodicity of a complex sound), stream segregation, automatic change detection, and multisensory integration". Also, as Zatorre et al. (2007) argue, neurons lateral to the PAC seem to be sensitive to the fundamental frequency of a complex tone, suggesting that these cortical areas are part of a hierarchical system responsible for pitch coding. Finally, after the transformation of acoustic features of the sound into auditory percepts realized by the auditory brainstem and the auditory cortices, the acoustic information is ready for conceptual and conscious processing (Zatorre, 1988; Koelsch, 2011).

During this process of extraction of auditory features of complex sounds, according to Koelsch's (2011) model of neural basis of musical perception, auditory sensory memory operations also take place and Gestalten representations of auditory features are formed. The auditory sensory memory network comprises areas located in the auditory cortices, as well as in the Frontal areas, including the Ventral Premotor Cortex (area BA 6), the Dorsolateral Prefrontal Cortex (BA 45) and the Inferior Frontal Gyrus (BA 44). Within these frontal areas, it is likely that the auditory sensory memory carry out operations such as attentional processing, sequencing and working memory processing (Schonwiesner et al., 2007). Also, during the Gestalten auditory formation process, a fine-grained process of grouping and separation of melodic, rhythmic and timbral features of the sound take place. This separation and grouping process of acoustic features of a complex sound are important in order to “establish a cognitive representation of the environment” (Koelsch, 2011, p. 4), since this process allows us to recognize acoustic objects – a similar operation takes place in order to distinguish the voice of an interlocutor from sounds of the environment. Linked to the Gestalten formation stage, temporal and inferior prefrontal regions, as well as the right Superior Temporal Gyrus (STG) perform the analysis of intervals between the tones of a chord or the tones of a melody, in order to specify whether the chord is major/minor, for instance. Finally, these processes that take place during the auditory sensory memory operations and in the Gestalten formation are linked with both working memory and long-term memory (Näätänen, Tervaniemi, Sussman, Paavilainen & Winkler, 2000; Berti & Schröger, 2003). As Koelsch (2011) claims, in order to carry out the structuring of acoustic features of a complex sound, structures in the working memory and long-term memory are required (e.g. our knowledge about melodic contours, tonal information, musical pieces, etc.). Very importantly to note, though, the brain mechanisms that underlie tonal knowledge in working memory may vary between musicians and non-musicians. Whereas non-musicians use overlapping structures of phonological loop of verbal working memory, which accounts for areas such as the PMd, the Planum Temporale, the Inferior Parietal lobe, the Anterior Insula and the Cerebellum, musicians have two different systems that account for the ‘tonal loop’ and phonological loop in working memory. Whereas the former comprise areas such as the right Globus Pallidus, right Caudate Nucleus and the left Cerebellum, the latter comprise the right Insular Cortex (Hickock, Buschsbaum, Humphries & Muftuler, 2003; Peretz & Coltheart, 2003; Koelsch, 2011).

Koelsch’s (2011) model of neural basis of music perception places particular interest in the relationship between the brain mechanisms activated in processing language and in music perception. More specifically, neuroimaging studies that investigated the brain mechanisms involved in the processing of musical syntax (the rules that govern melodic, rhythmic and harmonic construction according to the musical culture, like the function a chord has in a harmonic sequence in western music) observed that the Inferior Frontal Gyrus (BA 44), in particular its right hemisphere, the superior part of the Pars Opercularis, the anterior portion of the STG and the Ventral Premotor Cortex are implicated in the musical syntax processing (Parsons, 2001; Janata et al., 2002; Koelsch et al., 2002; Koelsch, Gunter, Wittforh & Sammler, 2005). It has been found out that the Inferior Frontal Gyrus (BA 44) is part of the Broca’s area involved in the processing of language syntax (Friederici et al., 2006), suggesting that the processing of both musical and language syntactic structures use some of the same cognitive mechanisms in overlapping brain areas. This suggestion is further evidenced by studies that used electroencephalography (EEG) and magneto encephalography (MEG), in which it was found out that the patterns of early right anterior negativity (ERAN) of the processing of chords with irregular functions in a harmonic progression interacted with the left anterior negativity (LAN) elicited by linguistic morpho-syntactic violations (Koelsch et al., 2005; Seinbeis & Koelsch, 2008). Very importantly to note, this ‘sophisticated’ mechanism in detecting violations in musical syntax is not only observed in musicians; non-musicians seem to acquire such knowledge of music syntax during their daily listening experiences (Tillmann, Bharucha & Bingan, 2000; Koelsch, 2011).

Likewise, by observing the N400, a negative *event related potential* (ERP), effect elicited after participant read a semantically unrelated word to a prime stimulus, which was either another sentence or musical excerpts, Koelsch et al. (2004) reported that the N400 effect (a negative deflection of peaks of ERPs that are part of the brain responses to visual and auditory words) patterns did not differ between the music and language priming conditions, since unrelated target words elicited a clear N400 effect when followed by the presentation of priming sentences or musical excerpts. The source of the N400 effect for both music and language primes was the posterior part of the Medial Temporal Gyrus (BA 21/37), an area implicated in semantic processing in language. These findings suggest that 1) both can have similar effects in terms of semantic processing of words, 2) music can activate representation of either concrete or abstract concepts, and 3) the cognitive mechanisms that decode semantic information in language can be identical to those that decode meaningful information from music.

Finally, in a model proposed by Zatorre et al. (2007), the authors suggest that distinct pathways emerge from the PAC, in which one stream is projected directly from the PAC within the temporal neocortex, another is projected towards the STG, and another, possibly, reaches the Ventral Stream and the Dorsal Streams. Whereas the former is regarded for extracting acoustic features that allow the identification of sound sources (Belin & Zatorre, 2000), the Dorsal Stream is regarded to play a similar role proposed for the Visual Dorsal Stream (Zatorre et al., 2007). Neurons located in the visual Dorsal Stream play a relevant role in the spatial processing of the visual stimulus (Rauschecker & Tian, 2000). Likewise, Zatorre et al. (2007) suggest that the Dorsal Auditory Cortical Pathway may play a similar role in terms of spatial processing of the sounds. These findings suggest that both the auditory and the visual system may share some of same principles of functional organization (Belin & Zatorre, 2000; Rauschecker & Tian, 2000; Zatorre et al., 2007).

Apart from the suggestion that both auditory and visual systems may share the same principles of functional organization, it has been proposed that the Dorsal Auditory Cortical Pathway (in short, the Dorsal Stream) may have a role in linking the auditory systems to the motor systems. Firstly, Zatorre et al. (2007) claim that this link would be plausible, since the Dorsal Stream is relevant for the spatial processing of sounds and for tracking its spectral energy (the energy in the frequency distributed in a given sound) over time, and bodily movements occur in both time and space. Secondly, as Hickock and Poeppel (2007) propose, the Dorsal Stream may play a role in speech processing, in particular, in the sensorimotor and phonological decoding. Thus, due to the computational capacities of the Dorsal Stream over spatial and speech processing, it has been proposed that the Dorsal Stream may be an interface between sensory and motor networks, in which motor signals would modify the activity from sensory structures (Rauscheker & Scott, 2009; Rauscheker, 2011). Thirdly, Warren, Wise and Warren (2002) suggest that the Dorsal Stream is implicated in the preparation of motor responses to auditory stimuli (e.g. arm movements towards sound location). Finally, anatomically, the Dorsal Stream links caudal auditory regions with Dorsal Frontal Premotor Cortices through Parietal Regions (Patel & Iversen, 2014). In line with the link between auditory and motor systems in music perception, the next section will thoroughly approach the involvement of motor areas in music perception, in particular, in beat perception.

3.1.2 Motor areas in music perception

As described in the last section, the auditory system is linked with the motor systems, and a good candidate for this link is the Dorsal Stream (Rauschecker & Tian, 2000; Zatorre et al., 2007; Rauscheker & Scott, 2009; Rauscheker, 2011). Also, a good amount of studies investigated the role of the Motor and Premotor areas during music perception, in special, during beat perception. Some of the findings that emerged from these studies will be described in this section.

First, when we listen to a musical rhythm we often respond to it by tapping along with the beat, nodding our heads or even dancing, in which we often seek to synchronize these motor actions with the beat of the musical piece (Chen et al., 2008b). The synchronization between our motor actions and musical rhythms can be observed in infants, in which even before having full control of their motor system move rhythmically in response to a rhythmic pattern they listen to (Martin, 2005; Phillips-Silver & Trainor, 2005; Zentner & Eerola, 2010). This synchronization between bodily movements and the music is known as *entrainment*.

Entrainment is a concept that emerges from complex systems theory, and this phenomenon occurs when “two or more independent oscillatory processes are synchronized with each other, gradually adjusting toward – and eventually locking into – a common phase and/or periodicity” (Krueger, 2013, p. 3). In the particular case of music entrainment, a self-sustaining oscillatory process in the brain, distributed through cortical and subcortical areas, entrain to the rhythm of auditory sequences of an input, allowing listeners to coordinate their perception and their reactive bodily behavior (e.g. foot tapping) with the musical rhythms as they occur in time (Glass & Mackey, 1988; London, 2004).

Jones and Boltz (1986, p. 466) describe the three primary stages of entrainment in human cognition: “1) perception, which primes the listener to form expectations; if expectations are met, then 2) synchronization; and if expectations are not met, then 3) adjustment or assimilation”. In other words, the synchronization is much related to our expectations of upcoming events, in the particular case being discussed in this section, the occurrence of the beats in a musical piece. This process may be facilitated according to how steady, or regularly patterned, the temporal events (in this case, the inter-onset temporal intervals between the beats in a musical piece) are. Discrepancies between our expectations about these temporal events and the temporal events themselves in the music may result in lack of synchronization, consequently, lack of entrainment (Clayton, Sager & Will, 2005).

Levitin et al. (2018, p. 56) claim that, in order to achieve entrainment, an "internal representation of the beat must exist". That is, in line with the perception stage of the entrainment process, people usually search for the beats of the musical piece ("finding the beat") and, once the beat is found, an internal representation of the beat is formed, and predictions are based on the detected structure, and this process is known as "beat continuing" (Povel & Essens, 1985; Grahn and Rowe, 2013). As Levitin et al. (2018) point out, these processes underlying beat perception and prediction engage the motor systems of the brain.

As such, several studies have been conducted in order to investigate the role of the motor areas of the brain in beat perception (e.g. Grahn & Brett, 2007; Chen et al., 2008a, 2008b; Grahn & Rowe, 2009, 2013). Overall, it has been observed an increase of brain activation in regions of the motor system such as the Premotor Cortex, the Basal ganglia and the SMA when subjects listened to monotone sequences of musical beats compared to when subjects were at rest (Grahn & Brett, 2007; Chen et al., 2008a; Grahn & Rowe, 2009).

More specifically, Grahn & Brett (2007) conducted a study that employed behavioral (reproduction task) and neuroimaging (fMRI) paradigms, in which subjects had to listen to three different types of rhythmic sequences, namely Metric Simple, Metric Complex and Non-metric. Very importantly to note, the authors classified each rhythmic sequence according to integer ratio relationship between beat intervals in a given sequence (Essens, 1986). Whereas in the Metric Simple condition the beat accents occurred at *regular* intervals (the beat accent always occurred in the beginning of each group of four units of beats), in the Metric Complex and Non-metric conditions beat accents occurred at *irregular* intervals (the beat accent occurred at distinct periods, not always in the beginning of each group of four units of beats, in which for the Metric Complex stimulus the same interval ratios as the Metric Simple was employed, and for the Non-metric, a distinct interval ratio to both former stimuli was used). After listening to these sequences, subjects had to reproduce them as accurately as possible. As a result, subjects reproduced the Metric Simple rhythms significantly better than the Metric Complex and Non-metric, respectively.

In another part of Grahn and Brett's (2007) study, subjects went through an fMRI brain scanning. During the scanning, subjects completed a discrimination task, in which they listened to a few sequences of beats and responded whether they were the same or not (again, the sequences comprised Metric Simple, Metric Complex and Non-metric rhythmic sequences). This task yielded no significant differences in discrimination across rhythmic sequences. Finally, apart from showing activation in the auditory areas, fMRI data showed higher activation in areas such as the Pallidum, pre-SMA/SMA, PMd, the Basal Ganglia, Cerebellum, superior and left inferior STG, Putamen, Ventrolateral Prefrontal cortex/insula bilaterally while subjects listened to any rhythmic sequences compared to rest. By comparing activation across rhythmic sequences, Grahn and Brett (2007) observed that Metric Simple sequences elicited significantly higher activation in the Pallidum, pre-SMA/SMA, and STG bilaterally compared to both Metric Complex and Non-metric sequences, respectively. Also, no significant differences were found between activation in any area of interest in the comparison between Complex and Non-metric sequences. Regarding the other areas of interest, none of them had higher activation in either Complex or Non-metric sequences compared to Metric Simple sequences. Finally, Grahn and Brett's (2007) study also investigated the differences in brain activation between musicians and non-musicians. As a result, Grahn and Brett (2007) observed that musicians had higher activation in areas such as the pre-SMA/SMA, Cerebellum and right PMd than non-musicians. A similar difference in brain activation in the motor areas between musicians and non-musicians are also observed elsewhere (Chen et al., 2008a, 2008b; Grahn & Rowe, 2009, 2013)

The findings that motor areas are engaged while subjects listen to distinct rhythmic sequences have been replicated in a good amount of studies. For instance, in Chen et al.'s (2008a) study, subjects had to tap along and synchronize their tapping with Metric Simple, Metric Complex and Non-metric structures. Meanwhile, subjects had their brain scanned by an fMRI scanner, showing that areas such as the left SMA, bilateral Mid-Premotor cortex, bilateral Ventral Premotor Cortex and left Premotor Cortex were significantly more activated during the listening and tapping compared to rest. Also, again, levels of activation varied across rhythmic sequences (Metric Simple, Metric Complex and Non-metric) participants listened and tapped to. In order to verify whether this activation was due to the motor action of tapping along with the sequences, in the second part of Chen et al.'s (2008a) study, subjects naively listened to the sequences and made no movements with their bodies meanwhile. Brain scanning results showed that similar motor areas were activated while subjects only listened to the sequences compared to rest, with a few differences between both conditions – the Ventral Premotor Cortex was not recruited during the naïve listening condition. Also, by investigating the brain mechanisms involved in 'beat finding' and 'beat continuation' previously highlighted in this section, Grahn and Rowe (2013) found that the Basal Ganglia and the SMA are involved in beat continuation, and not in beat finding. More specifically, subjects listened to either beat-based rhythmic sequences (e.g. Metric Simple sequences) that were preceded either by non-metrical sequences (in this condition, they would have to find the beat in the following sequence) or by another beat-based sequence (in this case, subject would have to just continue making predictions about the beat structure they were already acquainted of). As a result, Grahn and Rowe (2013) found higher activation in the Basal Ganglia and the SMA in the former condition compared to the latter, suggesting that these areas are more involved in predicting the following beats of a sequence once the temporal structure has been found than in synchronizing with the beat.

In line with the findings that the motor areas are engaged in rhythmic perception, it has been found that lesions in motor brain areas may impair beat perception to some extent. By comparing Parkinson's disease patients and control subjects' performance at a rhythmic discrimination task, in which subjects listened to a rhythmic structure (Metric Simple or Metric Complex) twice and had to point out whether the third rhythm was the same or not, Grahn and Brett (2008) observed that controls had significantly higher scores in the discrimination task when the third rhythm was Metric Simple than Metric Complex. On the other hand, the Parkinson's disease group did not yield any significant score differences in discrimination between the Metric Simple and Metric Complex rhythmic sequences. Interestingly, their discrimination levels in the Metric complex condition were similar to controls'. These results shed light on the Grahn and Rowe's (2013) claim above that the Basal Ganglia seems to be directly involved in beat processing, more specifically, in extracting the beat structure of beat-based rhythms, such as the Metric Simple sequence, since Parkinson's disease is characterized by loss of dopaminergic input into the Striatum and the impairment in the Basal Ganglia (Jellinger, 2001) and subjects from that group did not have better discrimination in Metric Simple structures compared to Metric Complex ones (Grahn and Brett, 2008). Likewise, Cope, Grube, Singh, Burns and Griffiths (2014) observed that patients with Huntington's disease and Multiple System Atrophy performed absolute and relative timing[14] tasks significantly worse than control individuals. Whereas the former disease is characterized by a predominant degeneration of the Basal Ganglia (more specifically, in the Striatum), the latter comprises a degeneration of the Striatum, Substantia Nigra and Cerebellum. Based on the data, Cope et al. (2014) conclude that the Basal Ganglia may mediate both relative and absolute timings mechanisms.

Apart from its engagement in music perception, more specifically, in beat perception, the motor areas also seem to be involved in music imagery. On this avenue of research, many studies have been carried out in order to examine the role of the motor areas in the imagery of music performance. As described in section 2.3 of the present study, Pascual-Leone et al. (1995) observed that subjects assigned to the mental training group of a five-finger exercise on the piano had similar patterns of increased activation in the motor areas compared to subjects assigned to the physical practice over the 5 days of experiment as the TMS showed. Apart from the role of motor areas in the imagery of music performance, Lima, Krishnan and Scott (2016) suggest that both the SMA and the pre-SMA are involved in auditory imagery of speech, syllables, words and music when subjects are instructed to generate auditory mental images in the absence of an auditory input. The activation of both areas has been reported in studies that employed neuroimaging techniques, such as fMRI , in studies in which subjects had to perform imagery of familiar tunes (Herholz, Halpern & Zatorre, 2012) or during the imagery of anticipation of sounds sequences (Leaver, Van Lare, Zielinski, Halpern & Rauschecker, 2009). As Zatorre and Halpern (2005) suggest, there seems to be a cross-modal interaction between different sensory modalities (in this case, auditory and motor) during the imagery of music. In line with this cross-modality interaction suggested by Zatorre and Halpern's (2005), the next section will discuss more about the effects of music on imagery.

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[14] As Leow and Grahn (2014) point out, absolute timing is necessary for perception of non-beat rhythms, such as Metric Complex or Non-metric. On the other hand, relative timing is necessary for beat perception of beat-based rhythms, such as the Metric Simple, since all intervals are encoded in relation to a beat interval.

3.2 Music and Imagery

In line with Zatorre and Halpern's (2005) cross-modality interactions between different sensory modalities during the imagery of music, some studies have investigated the actual effects of music listening on imagery, either visual or motor. This section will discuss some of these studies.

Most studies that investigated the effects of music on imagery focused on the visual imagery category. Firstly, perhaps in one of the first studies that investigated the effects of music on imagery, when subjects listened to synthesized music under relaxed conditions and reported their responses to music in a written form, by analyzing the content of responses into different categories, such as thoughts, emotions, sensations, and images, Osborne (1981) observed that the number of images responses were significantly higher than other categories' responses, suggesting that subjects had more promptly imagery responses when listening to music compared to other categories analyzed in the study. Quittner and Glueckauf (1983) investigated subjects' visual imagery production under the control condition (which consisted of subjects being instructed to imagine sitting on a bank of a river, followed by 3 minutes of free imagery), 3 minutes of deep relaxation, in which after relaxation they had to imagine a beach scene, and the listening of two selections of Steven Halpern's anthology volume 1, followed by free imagery. By comparing three variables, namely the vividness of imagery, the ease of evocation and the amount of imaging time, Quittner and Glueckauf (1983) observed significantly higher ratings in all of these variables when subjects performed imagery under the music condition compared to control and relaxation. Likewise, by comparing subjects' vividness of their own movements as an external viewer (visual imagery) or from an internal perspective (motor/kinesthetic imagery) while they listened to either upbeat (Kenny G's "Against Doctor's Orders"), slow music (Gymnopedies 1&2, by Erik Satie), or remained in silence (control condition), Tham (1994) observed that ratings of imagery vividness while subjects listen to both types of music were significantly lower[15] than control conditions. What is more, although Tham (1994) did not observe any difference in ratings of imagery vividness between music conditions, the author observed that ratings of motor imagery vividness were significantly lower than vividness of visual imagery across all three conditions.

The relation between music listening and imagery has also been the scope of studies in Music Therapy, giving rise to the Guided Imagery Music (GIM), a method in music therapy proposed by the music therapist Helen Bonny in the early 70's (Bonde, 1999). As Bruscia (2002, p. 46) defines, the specific method proposed by Bonny is described as "an individual form of exploring consciousness (e.g. in healing, psychotherapy, self-development, spiritual work) which involves spontaneous imaging in an expanded state of consciousness to pre-designed (taped) programs of classical music, while interacting with a guide, who uses nondirective, non-analytical, music-based interventions,

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[15] In order to measure the ratings of imagery vividness along the three conditions by which subjects were exposed to, Tham (1994) employed the Vividness of Movement Imagery Questionnaire (VMIQ) an instrument that uses a 5-point scale in which the lower the final score, the higher the imagery vividness reported by subjects.

within a client-centered orientation, all within a session that has the following components: preliminary conversation, relaxation induction, guided music-imaging experience, return, and postlude discussion”. In other words, the GIM is a method in which the client is invited to share the images produced during the listening of a pre-selected tape of classical music, and these images are discussed by the end of the session (Bonny & Savary, 1973; Juslin & Västfjäll, 2008). This method has been constantly modified as therapists may not follow all the GIM steps described by Bruscia (2002) or may have incorporated other musical genres into the pre-selected tape proposed by Bonny in the original description of the GIM method (Bonde, 1999; Perilli, 2017).

Apart from Tham’s (1994) work in which the relation between music and motor imagery was investigated, a few other studies approached this relation. Kuan, Morris, Kueh and Terry (2018) investigated whether elite shooters’ performance at a dart-throwing task would be facilitated by the combination of a dart-throwing-related imagery script and music after a 12-session program. By comparing the three conditions in which subjects were randomly assigned to, namely control (no music, imagery only), relaxing music (Frederick Delius’s Florida suite: III Sunset “Near the Plantation”) and arousing music (Edmond Luca’s Conquerors of the Ages “Attila the Hun”), Kuan et al. (2018) observed that dart-throwing scores were significantly higher for the relaxing music group compared to the arousing music and control groups, respectively. Further, arousing music group’s dart-throwing scores did not reach significantly differences compared to control group. Likewise, Karageorghis and Lee (2001) compared subjects’ performance at a muscular endurance task in which they had to hold the dumbbells in a cruciform position. Subjects were either assigned to motivational music group, imagery group or group that combined both music and imagery. As a result, Karageorghis and Lee (2001) observed that the task was better performed after subjects listen to music and performed imagery combined compared to the two other conditions. Finally, Debarnot and Guillot (2013) investigated whether music tempo affected the temporal congruence between physical walking (physical practice) and imagined walking (motor imagery). Subjects had to perform both tasks while listening to fast music, slow music and in silence. As a result, the authors found out that, compared to silence condition, the ability to achieve temporal congruence between both physical and imagined walking significantly decreased when subjects performed the tasks under the slow music and fast music, respectively.

Interestingly, two lines of explanation have been used in order to account for the results of the experiments described above. First, Tham (1994) hypothesizes that after listening to either slow or upbeat music, music activated or primed the right hemisphere of the brain, in which, as the author claims, is where “concurrent imagery experiences can be processed” (p. 40). On the other hand, control condition did not elicit any priming effect on the right hemisphere of the brain, thus imagery performance was not enhanced under this condition. Alternatively, in order to account for the results of their study, Kuan et al. (2018) measured subjects’ physiological signals (galvanic skin response, peripheral temperature and heart rate) while subjects listened to both the dart-throwing-related imagery script and to either relaxing music, arousing music or no music. As a result, Kuan et al. (2018) observed that the physiological indices measured reflected on lower arousal for subjects assigned to relaxing music group compared to the arousing group and non music group. Based on these data, the authors hypothesize that the combination of relaxing music + imagery led to arousal decrease, which, in turn, led to a better performance at a fine motor skill-related task, such as dart-throwing.

In line with Kuan et al.'s (2018) account for the results observed in their data, Ballan and Abraham (2016, p. 170) propose that "for the GIM method to be successful, multimodal neurons and neurons susceptible for cross-modal influences, in both cortical and subcortical areas, must cooperate to promote homeostasis (…)". In other words, Ballan and Abraham (2016) claim that by reducing the activation of Hypothalamic-Pituitary-Adrenal axis (HPA), the GIM method, which originally combines relaxation induction, listening to classical music and imagery, may regulate the client's stress and arousal levels, as well as their emotions, ultimately promoting homeostasis. Likewise, reduction in cortisol levels decreased when subjects took part in a GIM session, compared to silence (McNinney, Antoni, Kumar, Tims & McCabe, 1997). Additionally, Chanda and Levitin (2013) claim that music modulates the HR, body temperature, galvanic skin response, and muscle tension, in which slow music is usually associated with decrease in heart rate, respiration and blood pressure. All in all, as Kuan, Morris and Terry (2017, p. 3) point out, relaxing music is likely to create a "less tense, less formal, and less restrained environment for imagery" possibly due to its characteristics, such as repetition, predictability in melody, harmony and rhythm, and the slow tempo (Juslin, 2008). As a result, the physical relaxation that emerges from music listening may enhance cognitive responses, including better visual/motor imagery performance. The next section will further explore these two different accounts, namely the priming/activation proposed by Tham (1994) and imagery as a consequence of change of arousal levels after listening to music (Kuan et al., 2017, 2018) in regards to the improvement in spatial-temporal tasks after listening to music, known as the Mozart Effect (Rauscher et al., 1993).

3.2.1 The Mozart Effect

Apart from the studies that relied on subjects' self report about different features of imagery that emerged while they were listening to music, the effects of music on imagery have also been studied objectively by applying cognitive tasks that rely on imagery.

One of the most prominent studies that investigated the effects of music on imagery by applying spatial-temporal reasoning cognitive tasks was carried out by Rauscher et al. (1993). In that study, in the pre-intervention stage, subjects were assigned to three different conditions: music condition, relaxation condition and control condition. In the music condition, they listened to 10 minutes of Mozart's 448K Sonata, in the relaxation condition they listened to 10 minutes of relaxation structures to reduce blood pressure, and the control condition just remained in silence for 10 minutes. After the pre-intervention stage, subjects then completed a spatial-temporal reasoning task, such as pattern analysis test, a multiple choice matrices test and the Paper-Folding and Cutting (PF&C) multiple choice test. As a result, Rauscher et al. (1993) observed that subjects had significantly higher scores for these tests after listening to 10 minutes of Mozart's music compared to the other two conditions. Pulse rates were measured before and after listening conditions, yielding no interaction between listening condition and pulse times, therefore, excluding arousal as an explanation for the effect, according to the authors.

In subsequent works, the Mozart effect was further investigated in which other musical stimuli were employed alongside Mozart's 448K Sonata and control conditions. For instance, in Rauscher, Shaw, Levine and Ky's (1994) and Rauscher, Shaw and Ky's (1995) studies, subjects were divided into three groups, in which one group listened to Mozart's 448K Sonata, another to a mix of Phillip Glass' minimalist music, British trance music and a spoken story, and the third one remained in silence for 5 days. By comparing the groups' improvement, Rauscher et al. (1995) observed that the group that listened to Mozart's 448K Sonata for 5 days yielded higher improvement in the task compared to the other two. However, on the same study, the authors compared performance between these groups on a short-term memory task, observing that listening to Mozart's music yielded no significant differences in this specific test compared to the other conditions, suggesting that the Mozart Effect is likely to be specific to spatial-temporal reasoning tasks (Rauscher et al., 1995). The findings that listening to Mozart's music enhanced subjects' performance at spatial-temporal reasoning tasks (including MR of objects; e.g. Gilleta, Vrbancic, Elias & Saucier, 2003; Aheadi, Dixon & Glover, 2009) more than either control conditions or listening to other musical/auditory stimuli were reproduced elsewhere (e.g. Rideout & Labach, 1996; Rideout & Taylor, 1997; Rideout, Doherty & Wernert, 1998; Rauscher et al., 1997; Rauscher, Robinson & Jens, 1998; Xing et al., 2016).

The main hypothesis raised in order to explain the Mozart Effect relates to the *trion model* of the cortex, proposed by Leng and Shaw (1991). The trion model is a highly structured mathematical realization of the Mountcastle's (1979) organizational principle for the cerebral cortex, which proposes that "cortical column is the basic network in the cortex, and that is subdivided into small processing subunits or minicolumns (…)" (Leng, Shaw & Wright, 1990, p. 50). These cortical columns comprise a network of trions[16] with a large number of quasi-stable, periodic spatial-temporal firing patterns that can be excited and enhanced by a small change in connection strengths, giving rise to temporal sequences that last tens of seconds over large portions of the cortex (Leng et al., 1990;

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[16] As Leng and Shaw (1990) describe, a trion represents a mini column and is characterized for having localized, competing (between excitation and inhibition) and highly-structured interactions among other trions, in which the firing state of the network is updated by probabilistic rules that take into consideration the two previous states of each trion.

Leng & Shaw, 1991; Rauscher et al., 1995; Rauscher & Shaw, 1998). According to the trion model, these neural firing patterns occur symmetrically, and these symmetric operations are regarded as being a key feature of higher brain function, such as spatial-temporal reasoning (McGrann, Shaw, Shenoy, Leng & Matthews, 1994). Finally, according to Leng and Shaw (1991), exposure to music may excite these cortical firing patterns used in spatial-temporal reasoning, consequently affecting cognitive tasks that rely on this particular sort of reasoning. However, as Rauscher et al. (1994) claim, this change in firing patterns used in spatial-temporal reasoning is brought about by musical features that could be found in complex musical pieces, such as Mozart's 448K Sonata, not being replicated in pieces with highly repetitive structures, such as Phillip Glass' minimalist music [17].

In line with the trion model account for the Mozart Effect, brain-mapping studies have investigated the brain areas involved during the listening of Mozart's music. By comparing the differences in activation between Mozart's 448K Sonata and Beethoven's Für Elise through an fMRI, Bodner et al. (2001) observed that areas such as the Dorsolateral Pre-frontal Cortex, the Occipital Cortex and the Cerebellum (all areas expected to be important for spatial-temporal reasoning) had been more activated under Mozart's music compared to Beethoven's. Jausovec, Jausovec and Gerlic (2006), replicated the initial test conducted by Rauscher et al. (1993) and through an EEG, collected subjects' event-related desynchronization/synchronization while they listened to Mozart's 448K Sonata, remained in silent or listened to Brahm's Hungarian Dance. As a result, not only the subjects in the Mozart group outperformed those assigned to other conditions in the spatial-temporal reasoning tasks, but the authors also found that the Mozart group displayed less complex EEG patterns and more α band synchronization in task-relevant areas than controls, and less complex EEG patterns and more -1 α and γ synchronization in task-relevant areas than those who listened to Brahm's music. Also, Jausovec et al. (2006) found out that exposure to Mozart's music did not elicit any increase in arousal. As a conclusion for this study, Jausovec et al. (2006) claims that the changes spotted by the EEG are interpreted as if task-relevant brain areas were being activated during listening to Mozart's music, which may have contributed to the subsequent performance at the spatial-temporal reasoning task. Finally, Trimmel, Goger, Spitzer and Geiss-Ganadia (2017) compared the differences in DC potentials, a neurophysiological measure of activation process that measures attention-related activation, between Mozart's 448K Sonata, Albinoni's Adagio, Schubert's Fantasia in f-minor, and white noise. As a result, Trimmel et al. (2017) found that direct current (DC) potentials in prefrontal and frontal areas shifted negatively for Mozart's music, whereas for the other auditory stimuli they shifted positively, suggesting that Mozart's music enhanced attention for the processing of environmental information, which would consequently prime spatial information processing. In line

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[17] Despite using the term 'complex' to characterize Mozart's music, the Mozart Effect literature does not provide an objective account of why Mozart's music is considered 'complex', neither how this complexity would prime the cortical areas responsible for spatial-temporal reasoning, consequently enhancing subjects' performance after listening to Mozart's K448 Sonata. In other words, it is not clear, if anything, which musical elements in Mozart's music (e.g. harmony, melody, rhythm, all these elements combined, etc.) can be exactly regarded as 'complex' within the Mozart Effect literature.

with Jausovec et al.'s (2006) findings, Trimmel et al.'s (2017) study did not observe any relevant differences neither in autonomic responses (HR and SCR) nor in mood levels after subjects listened to each one of the musical pieces.

The Mozart Effect has sparked some controversy among the scientific community. Firstly, a good amount of work has attempted to replicate the Mozart Effect, however, with no success (e.g. Stough, Kerkin, Bates & Mangan, 1994; Newman et al., 1995; Weeks, 1996; Steele, Ball & Runk, 1997; Steele, Bass & Crook, 1999; McCutcheon, 2000). Secondly, in a meta-analysis conducted by Chabris (1999), by comparing Mozart's music and silence conditions, the author observed a very small effect size in performance on various spatial tasks when subjects listened to either Mozart's music or silence (d´ = 0.09), a slightly larger effect size in performance on specific spatial-temporal reasoning tasks, such as the PF&C (d´ = 0.14). However, Chabris (1999) observed a significantly larger effect size in performance of spatial-temporal reasoning tasks when comparing Mozart's music with relaxation instructions as a control condition. Thus, Chabris (1999) attributed the Mozart Effect to changes in subjects' arousal levels, since relaxation instructions tend to elicit a higher arousal decrease compared to listening to Mozart's music.

The arousal hypothesis has also been investigated as an account for the Mozart Effect. In Husain, Thompson and Schellenberg's (2002) study, the authors manipulated Mozart's 448K Sonata. By editing the original version, the authors created four different versions of the piece, in which one had major mode and fast tempo, the second version had major mode and slow tempo, the third version had minor mode and fast tempo, and the fourth version had minor mode and slow tempo. The authors hypothesized that the mode of the version (major or minor) would be correlated to changes in mood levels, whereas the major mode versions would increase the subjects' mood levels compared to baseline and the minor mode would have the opposite effect, and the tempo of the musical piece (fast or slow) would elicit higher arousal levels compared to baseline (fast mode) or lower arousal levels (slow mode). Subjects were randomly assigned to any of the four listening conditions and after listening to the pieces, completed the PF&C test. As a result, Husain et al. (2002) observed that subjects had better performance after listening to major-fast, minor-fast, major-slow and minor-slow, respectively. Also, measures of arousal and mood levels both before and after exposure to stimulus confirmed the authors' prediction about the reaction to the pieces would elicit on subjects' arousal and mood levels. Taken together, these results suggest that the Mozart Effect is an artifact of changes in arousal and mood levels, as Husain et al. (2002) claim.

In line with the arousal/mood hypothesis for the Mozart Effect, Schellenberg and Hallam (2005) compared children's performance at the PF&C test after they either listened to Blur (a British Pop-Rock band), Mozart's 448K Sonata and listened to the instructions to carry out the task. As a result, subjects had better performance after listening to Blur compared to the other two conditions. The authors hypothesized that children had better performance after listening to Blur as a consequence of a more enjoyable and pleasant experience they had compared to listening to the other two stimuli. This enjoyment and pleasure would be likely to set children in an optimal emotional state to perform the task. Likewise, Nantais & Schellenberg (1999) compared the subjects' performance at the PF&C after they listened to Mozart's music and to a Stephen King's narrated novel. As a result, subjects who enjoyed Mozart's music more than Stephen King's story had better performance at the PF&C after they listened to Mozart, and the opposite pattern was observed for those who preferred the novel over Mozart's music.

Taken together, the Mozart Effect and the different accounts for the effect described in this section partly laid the foundations for the experiment proposed in this study in terms of procedures realized and the hypotheses raised for the results. The hypotheses and the objectives of the present study will then be presented in the next section.

4 Objectives and Hypotheses

To summarize what has been discussed so far in the present study, there are pieces of evidence that suggest that simulation of motor actions are carried out in modality-specific systems of the brain, in which some of the brain areas that are involved in motor imagery are also involved in motor preparation and execution, such as, for instance, the Premotor Cortex (Decety et al., 1994), the Basal Ganglia and the Putamen (Gerardin et al. 2000), the Pre-frontal Cortex (Frith et al., 1991), the Premotor Cortex (Porro et al., 1996) and the SMA (Roland et al., 1980). Likewise, according to conceptual embodiment described in section 1.3, all concepts are grounded in modality-specific systems (strong embodiment) or some concepts are grounded in modality-specific systems of the brain (weak embodiment), as Mahon describes (2015). The case of motor imagery would relate, then, to weak embodiment, since it claims that motor concepts deployed in motor imagery are grounded in modality-specific systems of the brain. Both strong and weak embodiments are forms of ECT, in which the body can play a strong constraining role and a physically constitutive role in cognition (Wilson and Foglia, 2017). Finally, there is also suggestive evidence that MR tasks of bodily-related pictures are performed by means of motor imagery, relying on modality-specific systems of the brain, namely, the motor cortices (e.g. Parsons et al., 1994, 1995; Kosslyn et al., 1998).

On the music section of the theoretical background chapter, the brain areas involved in music perception, and more specifically, in perception of rhythmic structures of the brain were discussed about. By employing brain-mapping techniques such as fMRI, it was observed a correlation between activation in the motor areas of the brain, such as the SMA, Basal Ganglia and Putamen, PMd, superior and left inferior STG and Ventrolateral Prefrontal Cortex/ Insula bilaterally when subjects listened to monotonic sine tones with different rhythmic patterns, namely Metric Simple, Metric Complex and Non-metric (Grahn & Brett, 2007; Chen et al., 2008a, 2008b; Grahn & Rowe, 2009, 2013), in which higher activation in these areas were observed when subjects listened to Metric Simple rhythmic structures compared to Metric Complex and Non-metric rhythms (Grahn & Brett, 2007). Somewhat related to these findings, one of the hypothesis about Mozart Effect is the priming of brain areas involved in spatial-temporal reasoning, in which, according to the trion model (Leng et al., 1991), exposure to music may excite these cortical firing patterns used in spatial-temporal reasoning, consequently affecting cognitive tasks that rely on this particular sort of reasoning. According to this hypothesis, this priming in areas involved in spatial-temporal reasoning due to listening to complex music such as Mozart's 448K Sonata would explain the enhancement in performance that subjects showed in spatial-temporal reasoning tasks (including MR tasks; e.g. Gilleta et al., 2003; Aheadi et al., 2009) compared to control conditions and relaxation instructions (e.g. Rauscher et al., 1993, 1994, 1995, 1998; Rideout & Labach, 1996; Rideout & Taylor, 1997; Bodner et al., 2001; Jausovec et al., 2006).

The empirical findings and theoretical assumptions described in the former sections of the present study give rise to the assumptions that have been used in order to motivate and draw hypotheses upon the experiment proposed and carried out in the present study. These assumptions are:

(I) Weak embodiment: *some* concepts are the simulations of perceptual, motor and introspective experiences, grounded in modality-specific systems of the brain (Mahon, 2015).

(II) Motor imagery is the simulation of bodily movements, carried out in modality-specific systems of the brain, namely, the motor cortices (Jeannerod, 2006).

(III) MR tasks of bodily-related pictures are accomplished by means of simulation of one's own bodily movements to accomplish the task (Wexler et al., 1998).

(IV) Music activates the motor cortices of the brain, and this activation varies in degree according to the rhythmic complexity of the auditory stimulus, in which metric simple rhythmic structures elicit higher neuronal activation in these brain areas than metric complex and non-metric rhythmic structures (Grahn & Brett, 2007).

(V) Increase of cortical activation and synchronization of specific brain areas used for cognitive tasks after music listening results in performance enhancement at the task compared to control conditions and other stimuli (Rauscher et al., 1993).

(VI) Increase of cortical activation and synchronization of specific brain areas used for cognitive tasks after music listening are the reason why the Mozart Effect is possible, and not subjects' increase of arousal/mood levels or subjects' preference for a stimulus (Rauscher et al, 1995; Bodner et al., 2001).

In the light of the assumptions outlined above, the experiment proposed in this study has been designed to investigate the influence of distinct auditory stimuli, namely *Metric Simple*, *Metric Complex* and *Silence* on MR of bodily-related pictures of a homogeneous group of non-musicians.

Hence, the overall research question of the study is ***does listening to music enhance performance at MR of bodily-related pictures?***

Apart from the overall research question described above, the results of the experiment may address to other specific questions, such as:

- **A)** Are motor concepts grounded in modality-specifics systems of the brain, as suggested by the weak embodiment in virtue of experimental findings about motor imagery (e.g. Jeannerod, 2001)?
- **B)** Do the non-neural parts of the body play a constraining role in cognition? (e.g. Parsons et al., 1987a, 1987b)
- **C)** If there are significant differences in performance after subjects listened to distinct auditory stimuli, are these differences due to brain activation elicited by the music, as proposed by Rauscher et al. (1993) or changes in arousal/mood levels (Husain et al., 2002) or preference for a given stimulus (Nantais & Schellenberg, 1999)?

In line with the assumptions (**I-VI**) highlighted above and the questions (**A-C**), the hypotheses for the experiment are:

- **1)** From assumptions (**I-V**), it is expected that *after listening to Metric Simple Music, subjects will have significantly better performance at MR of bodily-related pictures compared to Metric Complex Music and Silence.* This hypothesis sheds light on question **A** outlined above. First, if this hypothesis is true, then we would have some evidence that weak embodiment of concepts is true. More specifically, if music activates the motor cortices (according to assumption **IV**), and we perform MR of bodily-related pictures using modality-specific systems of the brain, such as the motor cortices (**II, III**), then the claim that some concepts (in this case, motor concepts deployed in motor imagery tasks) are grounded in modality-specific systems (weak embodiment claim) might be true. Thus, if weak embodiment is true, then question **A)** is addressed. If weak embodiment is true, it could be the case that both constraining and constitutive roles of the body in cognition are true as well. As Barsalou (1999) claims, concepts are grounded in modality-specific systems through perceptual symbols, being processed by simulations. These simulations, as Barsalou (1999, p. 618) points out, are the "reenactment of perceptual, motor, and introspective states acquired during experience with the world, body and mind". If the simulations of the kinds of experiences we have had actually form the concepts we use to think about motor actions, then it could be the case that motor actions we have had in the past are constitutive of motor concepts. In other words, it seems like the body, in this case, is constitutive for cognition because the kinds of bodily experiences we have had in the past (in this particular case, motor actions) shape the ways of thinking about motor actions, which in turn plays a role in forming concepts related to motor actions. Also, as pointed out in section 1.3, weak embodiment is also consistent with body as a constraint on cognition, addressing question **B)**. If motor concepts are driven by simulations of past motor actions experiences, and these experiences rely on bodily structures, then the way we think about motor actions might be constrained by the past experience we have had in the past. Finally, the research question outlined above would also be addressed. According to the hypothesis outlined in this paragraph, after listening to Metric simple music, subjects will have their performance enhanced compared to the other two stimuli, contrary to Rauscher et al.'s (1993, 1994, 1995, 1998) assumption that complex music accounts for activation of brain areas involved in the task. Since music primes cortical areas responsible for cognitive task enhancement in performance (**V**), MR of bodily-related pictures are accomplished by means of motor imagery in the motor cortices (**II, III**), and listening to music (particularly, its rhythmic elements) activates the motor cortices, varying in degree according to rhythmic complexity (**VI**), then it is hypothesized that, if these assumptions are true, Metric Simple Music would enhance performance in MR of bodily-related pictures more than the other two conditions, reflecting on faster RTs and higher ACC levels when the MR of bodily-related pictures is performed after subjects listened to Metric Simple Music compared to the other two stimuli.

2) In line with the hypothesis **1)** outlined in the last paragraph and assumptions **I-VI,** *it is expected that increase in performance after subjects listened to Metric Simple Music compared to Metric Complex and Silence, respectively, because music would have activated cortical areas used in MR of bodily-related pictures, and not because there would have been a significantly difference in arousal/mood levels or subjects had any preference for the stimuli.* As it will be fully described in the methodological section of the present study, a few instruments will be used in order to assess arousal (the Self-Assessment Manikin - SAM; Bradley & Lang, 1994) – and mood levels (Profile of Mood States - POMS; Viana, Almeida & Santos, 2001), as well as the valence of the stimuli (SAM; Bradley & Lang, 1994) before and after subjects listen to each auditory stimuli. In line with previous works (Rauscher et al., 1993; Jausovec et al., 2006; Trimmel et al., 2017), it is predicted that there will be no significant differences in arousal/mood levels before and after subjects listened to the stimuli nor valence ratings after stimuli exposure, providing suggestive evidence that the possible Mozart Effect is due to direct brain activation of areas involved in MR of bodily-related pictures (Rauscher et al., 1993, 1994, 1995, 1998). This hypothesis would address question **C)** apart from questions and assumptions already addressed by hypothesis **1)**.

3) Finally, in line with assumptions **III**, it is ultimately hypothesized that, replicating Parsons' (1987a, 1987b) findings, *the time to make a laterality judgment of a stimulus reflects the degree of MR needed to bring one's body parts to a position adequate for achieving the task, reflecting on an almost perfect linear increase of RTs with angular stimulus disparity.* It is predicted that this pattern of responses will be reflected across all auditory conditions (Metric Simple, Metric Complex and Silence). In sum, if MR task of bodily-related pictures is accomplished by simulations of bodily movements (**III**), then it is hypothesized that subjects will mentally rotate the body parts depicted on the screen as if they were physically rotating their own limbs (Wexler et al., 1998). Thus, it is hypothesized that RTs for this MR task will be significantly slower for bodily-related pictures with higher degrees of inclination departing from the canonical position (e.g. pictures of body parts depicted at 180º of inclination) compared to pictures that would resemble the canonical position of these body parts, with lower degrees of inclination (e.g. pictures of body parts depicted at 0º degree of inclination). Since subjects would employ the strategy of rotating the image of the body part up to the canonical position of their own body parts until they provide a laterality judgment response, it is plausible to hypothesize that RTs will reflect on the degrees of inclination of the body parts depicted on the screen. Likewise, ACC levels are expected to follow the same pattern as RTs, in which significantly higher ACC levels will be observed for pictures in a canonical position (0º) than for pictures that will require a larger rotation (180º). In sum, it is expected an almost linear increase in RTs and decrease in ACC levels according to the degree of inclination of each body part depicted on the screen, namely 0º, 30º, 60º, 90º, 120º, 150º and 180º. This hypothesis relates to question **B)** described above, in which the body plays a constraining role on cognition since subjects imagine carrying out bodily simulations (**III**) to accomplish the task and body biomechanically constraints is likely to a major role when subjects rotate body parts depicted in anatomically awkward positions (e.g. 180º) compared to canonical positions (e.g. 0º).

Also, as pointed out in the Mozart Effect section of the present study, there seems to be a lack of account of why Mozart's music can be regarded as complex within the Mozart Effect literature. In other words, Rauscher et al. (1993, 1994, 1995, 1998) seem to regard Mozart's music as a complex musical piece by comparing its structure with the structure of other musical stimuli, such as Phillip Glass's music, for instance. Phillip Glass's music is regarded as being highly repetitive and predictable, with no significant melodic, harmonic or rhythmic changes throughout the piece (Hetland, 2000). However, the Mozart Effect literature lacks objective explanation of why Mozart's music can be regarded as complex, or which specific element of Mozart's music accounts for its complexity (e.g. whether it is the melody, or the harmony, or the rhythm, or all these elements combined that account for the complexity of the stimulus).

In line with this lack of account over Mozart's music complexity, this study also aims to specifically investigate whether changing the rhythmic structures of a musical piece accounts for the possible Mozart Effect. Consequently, by changing the rhythmic structures of a musical piece with simple rhythmic structures into a musical piece with complex rhythmic structures, the latter stimulus would consequently be more complex than the former. By investigating whether a specific musical element accounts for the effect (in the case of this study, the rhythmic structures of a musical piece), it would then be possible to have a better understanding of the Mozart Effect and, if anything, which specific musical element accounts for the effect. However, due to the reasons pointed out so far, in special, in the light of assumption **IV**, it is expected that, contrary to Rauscher et al.'s (1993, 1994, 1995, 1998) hypothesis that listening to complexly structured music enhances performance at spatial-temporal reasoning tasks, listening to a musical piece with simple rhythmic structures (Metric Simple Music) would result in increase of neural activation in the motor areas and, consequently, performance enhancement at MR of bodily-related pictures compared to Metric Complex Music and Silence, respectively, as stated in hypotheses **1)** and **2).**

As it will be further described in the methodological section, particularly in the sub-section that refers to the auditory stimuli selection, selection of the two musical stimuli was based on a study carried out by Bouwer et al. (2018), in which the authors investigated what makes a rhythm complex by asking a large sample (N = 5297) to rate how complex the rhythmic structures they listened to according to their perception. Thus, music selection for the present study, and more specifically, the manipulation of rhythmic structures between the Metric Simple and Metric Complex pieces was based on the findings that emerged from a study that employed objective methods to discover what makes a rhythm complex and harder to be perceived compared to other rhythmic structures (in this case, a survey with a large sample).

As an alternative to hypotheses **1)** and **2)**, if Rauscher et al. (1993, 1994, 1995, 1998) are correct that music complexity is key to the Mozart Effect, and complexly structured music elicits higher activation and synchronization of neural patterns (**V**), it could be the case that subjects' performance at MR of bodily-related pictures after listening to Metric Complex Music could be significantly better compared to the other two conditions. That alternative would sharply contrast with assumption **IV** outlined above.

Finally, in case either one or both hypotheses **1**), **2**) and **3)** described above are not verified by the experiment, it could be the case that one or more assumptions (**I-VI)** listed above may not be true. If that is the case, then a thorough discussion regarding the assumptions outlined in this section will be carried out in the discussion section of the present study, in the light of experimental results.

II. Method

1 Subjects

The experiment was approved by the Ethical Committee of the University of Lisbon.

36 (thirty-six) students of Sports Science from the Polytechnic Institute of Castelo Branco (Mean age: 21.07 years old, Standard Deviation: 3.08), Portugal, participated voluntarily in the experiment. Subjects answered a demographic questionnaire along with the informed consent (**Appendix I**) informing their age, gender, nationality, and their level of musical expertise. The sample comprised 30 (thirty) males and 6 (six) females, in which a total of 5 (five) were left-handed. In order to define whether a subject was a musician or not, this study employed the same criteria as in Grahn and Brett's (2007) and Aheadi et al.'s (2009) studies. In those studies, subjects with five or more years of formal musical education and current regular musical activities were classified as musicians, and those with less than five years of formal musical education were classified as non-musicians. According to the questionnaire subjects answered in this study, all of them had less than five years of musical education, thus, all subjects were non-musicians.

This criterion of exclusion of musicians from the sample was opted in the light of previous studies described in chapter 1. This study aimed to investigate whether performance at MR of bodily-related after subjects were exposed to Metric Simple Music, Metric Complex Music and Silence would differ significantly. Grahn and Brett (2007) observed that musicians had higher activation in the motor areas during exposure to the stimuli compared to non-musicians. As hypothesized in the first chapter of this study, if activation in these motor areas leads to improvement in performance at tasks such as MR of bodily-related pictures, then musicians would have an advantage over non-musicians. Thus, it was opted to recruit subjects that would form a homogeneous group, in this case, students of sports that had no previous formal musical education. This limitation is addressed in the section that describes the limitations of the present study and in the suggestion for future studies.

Apart from the criterion of exclusion elucidated above, it was also asked in the questionnaire whether subjects had a sight/hearing deficit that would impair their performance at the MR of bodily-related tasks (in this particular case, a visual deficit) or during the auditory phase of the study (hearing deficit). All subjects reported having no sight/hearing deficit, being sound for the experimental tasks. Finally, no subject reported a major health issue that would impair their performance at the task.

The last criterion of exclusion adopted in the present study relates to subjects' motor imagery abilities. As such, subjects filled out the Movement Imagery Questionnaire 3 (MIQ3; **Appendix II**) adapted to European Portuguese (Mendes et al., 2016), in which they had to imagine carrying out motor actions through a 1PP or 3PP. The difficulty to imagine these movements were rated on a Likert-scale ranging from 1 ("very difficult to image") to 7 ("very easy to imagine"), and the threshold of 36 points at the MIQ3 was established as a criterion of exclusion, since scores under 36 points at the MIQ would mean that subjects would have poor imagery abilities. All subjects scored at least more than 36 points in total (Mean = 64,33; SD = 14,08), generating no exclusions on the basis of low scores at the MIQ3 adapated to European Portuguese (Mendes et al., 2016).

Sample size was based on Rauscher et al.'s (1993) study about the Mozart Effect, in which the authors recruited 36 subjects to participate in their experiment. Also, since subjects were assigned to groups that were counterbalanced and received each pre-treatment (in this case, an auditory stimulus) in different orders, six different groups were created to satisfy all order possible of exposure to auditory stimuli across the three days of experiments, as it will be more detailed in the experimental design section. Thus, the sample size had to be a number multiple of 6 (six), and 36 (thirty-six) fills in this requirement.

2 Materials

2.1 Selection of musical stimuli

Subjects were exposed to three different auditory stimuli prior to the completion of MR of bodily-related pictures. Since this study aims to specifically investigate whether the rhythmic structures of a musical piece accounts for the possible Mozart Effect in the light of assumption **IV** outlined in the objectives and hypotheses section, that claims that music activates the motor cortices of the brain, and this activation varies in degree according to the rhythmic complexity of the auditory stimulus (Grahn & Brett, 2007), two different musical stimuli were used as auditory stimuli before subjects completed the MR of bodily-related pictures.

As such, a minimalist/techno musical piece written by Motorcity Soul named "Space Katzle" was selected (Supplementary Material). This musical piece is characterized for the lack of structural changes in its rhythm, in which the kickdrum beats remain regularly grouped in a simple quadruple meter (4/4) for the whole duration of the musical piece, in which the accented note occurs in the beginning of each group of four units. In other words, the kickdrum beats occurred at *regular* intervals between each other, and this pattern of beat distribution and regular occurrence remains the same throughout the entire musical piece. Figure **2.1** depicts an example of a group of four beats regularly grouped in a simple quadruple meter (4/4). This rhythmic structure observed in Motorcity Soul's "Space Katzle" seems to fit Grahn and Brett's (2007) description of a Metric Simple rhythmic structure they used in their study, in which beat accents occurred at *regular* intervals, regularly grouped, in the beginning of each group of four units of beats, in the case of a quadruple 4/4 meter. Thus, since the rhythmic patterns of Motorcity Soul's "Space Katzle" fit the criteria of Metric Simple rhythmic structure described by Grahn and Brett (2007), this musical piece was selected as the music sample used as the *Metric Simple Music* auditory stimulus in the experiment.

Apart from the drumbeats, the rhythmic section of the musical piece also comprised other musical instruments, such as egg shakers, hi-hat, woodblock, and cymbals. The rhythmic structures of these instruments followed the same Metric Simple pattern, in which the beats were also regularly grouped within a simple quadruple meter. Also, the musical piece consisted of other synthesized musical instruments that formed the melodic and harmonic section. In order to highlight the rhythmic section of the musical stimulus over melodic and harmonic features (since the rhythmic features of the music is the variable being studied), a music editing software called Ableton Live 10 was used. Thus, for this Metric Simple version of “Space Katzle”, the original version was edited, for which the loudness of the kickdrum beats and other rhythmic instruments were raised by 10 decibels (dB) compared to the synthesized instruments that formed the melodic and harmonic sections of the musical piece.

Finally, the original version of “Space Katzle” can be regarded as belonging to a minimalist techno genre. This musical genre is characterized by the lack of structural rhythmic/melodic/harmonic changes throughout the musical piece, being highly repetitive at times (Rauscher et al., 1994). The total duration of this musical piece was 08:25, the same as Mozart’s 448K Sonata.

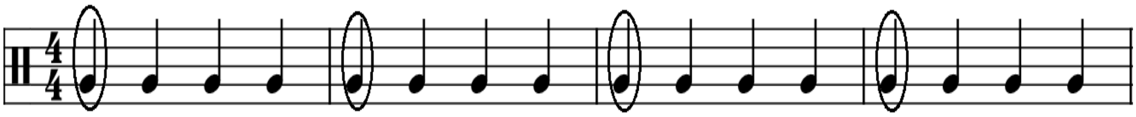



Figure 2.1 An illustration of groups of beats regularly grouped in four bars of a simple quadruple meter (4/4). The beats within the circles are the accented ones, placed in the beginning of each bar. Musical sheet rendered through www.noteflight.com

For the Metric Complex version of “Space Katzle”, the original version was also edited. However, contrary to the Metric Simple version, the edition was more elaborated than altering the loudness of the rhythmic components of the musical piece in order to highlight them over synthesized instruments that formed the musical piece’s melodic and harmonic structures. The editing of the Metric Complex version was based on Grahn and Brett’s (2007) and Bouwer et al’s (2018) definitions of Metric Complex rhythmic structures. According to Grahn and Brett (2007), in a Metric Complex rhythmic structure, beat accents occurred at *irregular* intervals. In other words, unlike the Metric Simple rhythmic structure, the beat accent occurs at distinct periods, not always in the beginning of each group of four units of beats. The beats are not regularly grouped together along the quadruple meter (4/4) structure, so the first note of a group of four units of beats is not always the accented one. By carrying out a survey with 5297 subjects, Bouwer et al. (2018), subjects had to rate the rhythmic complexity of a musical stimulus, in which subjects had to rate how difficult it was to find and follow the beat. As a conclusion for that study, Bouwer et al. (2018) found out that in rhythmic structures with accents missing in the beginning of the grouping of four beats, the beat is more difficult to find and rhythmic perception may be impaired as a consequence. Also, musical novices rated rhythms with some accents off the beat (i.e. 5 offbeat accents in a grid of 16 beats) as slightly more difficult than those with few accents off the beat (i.e. 1 offbeat accent in a grid of 16 beats), regardless of the number of beats missing from the group of beats in a quadruple meter (4/4) structure. In sum, Bouwer et al's (2018) objectively measured what are the key features that make a rhythmic structure hard to perceive by exposing subjects to 60 different monotonic samples with distinct rhythmic sequences and asking them to rate the complexity of each sequence on a scale from 1 (very easy) to 10 (very difficult), according to their own perception.

In line with Grahn and Brett's (2007) and Bouwer et al.'s (2018) studies on rhythmic perception and definitions of Metric Complex rhythms, the original version of "Space Katzle" was then edited with Ableton Live 10, in which some of the beats from the synthesized instruments that formed the rhythmic section of the original tune, such as the kickdrum, the hi-hat, the woodblock, the egg shaker, and the cymbals were removed from the places where they were positioned in the original version. In other words, in line with Bouwer et al. (2018) findings, some of the beats that were originally placed in the beginning of the grouping of four other beats were removed and placed in offbeat positions along the simple quadruple meter (4/4). Figure **2.2** depicts an example of a group of notes not placed regularly along a few bars of a simple quadruple meter, constituting a Metric Complex rhythmic structure, according to Grahn and Brett (2007). In sum, the rhythmic structure designed in this new version of "Space Katzle" seems to fit Grahn and Brett's (2007) description of a Metric Complex rhythmic structure; thus, this version was used as one of the experiment's auditory stimuli, namely, *Metric Complex Music*. The total duration of this musical piece was, like the Metric Simple version, 08:25.

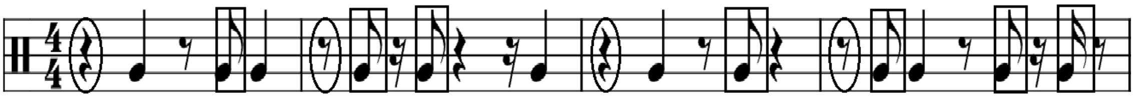



Figure 2.2 An illustration of groups of notes not regularly grouped along four bars of a simple quadruple meter. The circled beats represent the missing beats in the beginning of each bar. The beats within the rectangles represent the beats placed in offbeat positions. Musical sheet rendered through www.noteflight.com

There are a few reasons why Mozart's 448K Sonata used in Rauscher et al.'s (1993, 1994, 1995, 1998) and in most studies about the Mozart Effect was *not* used in the present study. First, although listening to Mozart's music improved subjects' performance at spatial-temporal reasoning tasks compared to other musical stimuli and control conditions (e.g. Rauscher et al., 1995), in some studies the same effect was observed with other musical stimuli (e.g. Rideout et al., 1998; Nantais & Schellenberg, 1999). It has also been found that subjects who listened to musical stimuli from musical genres other than classical music (e.g. Pop Rock) outperformed those who listened to Mozart's music at a spatial-temporal reasoning task (Schellenberg & Hallam, 2005). Thus, the Mozart Effect has been observed when musical stimuli other than Mozart's 448K Sonata was employed, meaning that the Mozart Effect is not specific to Mozart's music. Secondly, in order to investigate assumption **IV** described in the objectives and hypotheses section of the present study, two musical samples with distinct degree of complexity, namely Metric Simple and Metric Complex, would have to be generated. Mozart's music would not have been the most suitable stimulus to be employed in order to investigate this particular assumption for a couple of reasons. First, since Mozart's music does not employ a particular rhythmic instrument (it is a four-hand piano musical piece), changing Mozart music's rhythm would necessarily affect other musical features of the musical piece, such as its melody. Thus, the rhythm variable would not have been the only variable changed in the edition. Secondly, classifying Mozart's music in terms of Metric Simple or Metric Complex, in the light of Grahn and Brett's (2007) definition, would not be as clear as the attribution of Metric Simple to "Space Katzle's" original version due to the reasons highlighted above. Mozart's music has a few rhythmic variations in which the tempo changes throughout the piece. In other words, the musical piece either speeds up or slows down at some stages. Finally, as it will be discussed in the procedural design below in this chapter, subjects were asked to pay attention to the rhythmic structures of the musical stimuli, in which they were asked by the end of musical listening if they had found the rhythmic structures easy or difficult to follow on a scale from 1 (very difficult) to 9 (very easy). Due to the lack of rhythmic structures such as groups of beats in Mozart's music and subjects' lack of musical expertise, this discrimination task would probably not have been possible.

In line with the majority of the studies about the Mozart Effect, silence was selected as an auditory stimulus correspondent to control condition.

2.2 Bodily-related pictures

For the MR of bodily-related pictures task that subjects carried out in the experiment, pictures of hands and feet (**Appendix III**) were selected and manipulated through Microsoft Office Picture Manager. This manipulation consisted of rotating the pictures into new degrees of inclination from the canonical (0º degree) position. The new degrees of inclination were 30º, 60º, 90º, 120º, 150º and 180º, and all of them, apart from the pictures displayed in 180º, were inclined both to the right hand side (clockwise) and to the left-hand side (anti-clockwise) from the canonical position. Thus, 336 was the total amount of images selected to be used in the experiment. These pictures formed the critical block list. Pictures of left and right hands and feet were equally distributed across the block lists, appearing randomly on the screen. For the practice trials, 72 more pictures of hands and feet were selected (**Appendix IV**). Figures **2.3** and **2.4** are examples of pictures displayed in the canonical position of the human anatomy (0º) and inclined in 150º to the right hand side. Those trials were not computed.

Figure 2.3: Picture of a human hand displayed in the canonical position of the human anatomy (0º of inclination).

Figure 2.4: Picture of the same human hand as Figure **2.3** inclined in 150º to the right-hand side (clockwise) from the canonical position (0º).

The bodily-related pictures were presented through E-Prime version 2.37, and were divided into 8 block trials of 14 pictures each. Every block trial had the same number of bodily-related pictures oriented in all seven different degrees of inclination (0º, 30º, 60º, 90º, 120º, 150º, and 180º). Each trial started with a fixation cross displayed at the center of the screen for 500ms, which was also displayed between the appearances of each picture for 300ms. A feedback was provided for every correct and incorrect responses provided by the subjects. This feedback notice remained displayed for 300ms between each picture appearance. Also, two practice blocks with 14 pictures each were added to the whole trial blocks; however, these practice trials were not computed. The 8 blocks were presented randomly across the 3 days of experiment, as well as the two practice blocks. The order of presentation of pictures was also randomized within the block trials and practice trials. All pictures were presented at the center of the computer screen.

2.3 Apparatus

Two apparatus were used in order to present subjects with the auditory stimuli and the bodily-related pictures for the MR task.

First, musical stimuli were reproduced through a JBL Xtreme Black 2.0 speaker. The musical stimuli were stored in the experimenter's mobile phone, a TP-Link Neffos X1 Max, and they were reproduced via Bluetooth connection with the speaker. The JBL Xtreme Black 2.0 speaker was placed in the middle of a round table, and subjects were asked to sit comfortably on chairs around the speaker. Volume was set to 56dB, and experimenter always asked subjects if that volume was too loud or too low. Subjects never complained about the volume of the musical stimuli.

Bodily-related pictures were presented through a software for Psychological tests called E-Prime version 2.37, which was installed in different computers at the Polytechnic Institute of Castelo Branco. All computers had Windows 10 installed; however, some of them were portable laptops (4), while others had a System Unit (2), not being portable. Although the former types of computers had smaller screens than the latter types (13,3" x 17", respectively), resolution was 1366 x 768 pixels for all of them. Thus, the size of the images did not differ from one computer to another. Subjects were asked to use the same computer across the 3 days of experiments. All pictures were displayed on colors. Brightness of the pictures may have differed from one computer to another since they were equipped with different graphics systems. However, this variable may not have interfered with the completion of the tasks. Finally, subjects seated straight in a chair in front of their computers, approximately 20cm away from the computer screen.

3. Experimental design and procedures

3.1 Counterbalanced paradigm

In line with previous Mozart Effect experiments (e.g. Rauscher et al., 1993; Rideout et al., 1998; Gilleta et al., 2003) and studies that measure the effects of music on imagery (e.g. Quittner & Glueckauff, 1983), the present study employed a counterbalanced paradigm, in which all subjects were exposed to all three different auditory stimuli (Metric Simple Music, Metric Complex Music and Silence) in different orders. Subjects (N = 36) were divided into 6 groups of 6 individuals each (1 female per group), satisfying all possible combinations of order of auditory stimuli presentation. Table **2.1** describes the order in which each group was presented with the auditory stimuli along the three days of experiment.

	Session 1 Auditory Stimulus	**Session 2** Auditory Stimulus	**Session 3** Auditory Stimulus
Group 1	Silence	Metric Simple Music	Metric Complex Music
Group 2	Metric Simple Music	Metric Complex Music	Silence
Group 3	Metric Complex Music	Silence	Metric Simple Music
Group 4	Silence	Metric Complex Music	Metric Simple Music
Group 5	Metric Simple Music	Silence	Metric Complex Music
Group 6	Metric Complex Music	Metric Simple Music	Silence

Table 2.1: Order of auditory stimulus presentation to each group along the three days of experiment. Each session represents a day of experiment; thus, session 1 = day 1, session 2 = day 2, and session 3 = day 3.

As described in the section regarding selection of bodily-related pictures, the order of block trials was also randomized and presented in different orders throughout the three days of experiment; thus, subjects made a laterality judgment to all bodily-related pictures that were selected and presented.

According to Pollatsek and Well (1995), counterbalancing order of auditory stimuli presentation is suitable to control for order effects that experiments that employ repeated-measures design might convey. For instance, assuming that subjects were exposed to all three different auditory stimuli in the same order during the three days of experiment (e.g. first day – Silence, second day – Metric Complex Music, third day – Metric Simple Music), subjects could have had better performance when exposed to the Metric Simple Music than to the other two auditory stimuli because they are more familiar with the testing environment or the task of MR of bodily-related pictures itself. Alternatively, exposing subjects to all treatments in all orders possible may attenuate this issue (Myers, Well & Lorch Jr, 2010). Thus, assuming that subjects are sensible to practice and improve their performance throughout the three sessions, since different groups performed the task after exposure to different auditory stimulus, this particular improvement would not have been due to a particular stimulus, but would rather be due to practice effect. Thus, the order effect, in this case, would be controlled.

3.2 Experimental procedures and instruments

After answering the demographic questionnaire (**Appendix I**) and the MIQ3 adapted to European Portuguese (**Appendix II**; Mendes et al., 2016), subjects were randomly assigned to one of the six groups described in counterbalanced paradigm section above.

On the first day of experiment, subjects were briefed about the tasks they would be doing. First, subjects were asked to fill in the SAM (**Appendix V**; Bradley & Leng, 1994) and the POMS adapted to European Portuguese (**Appendix VI**; Viana et al., 2001) before starting with the listening task. These two instruments were chosen as instruments to measure subjects' arousal and mood levels during the experimental procedures in the light of Husain et al.'s (2002) study.

First, in that study, Husain et al. (2002) employed similar self-report instruments in order to assess subjects' arousal and mood levels before and after exposure to distinct versions of Mozart's music. These instruments that measure arousal and mood levels based on subjects' self-report are regarded as valid by some authors (Thayer, 1970; Dermerd & Berscheid, 1972; McNair, Lorr & Droppleman, 1992; Husain et al., 2002), in which the correlation between the self-report and physiological measures, such as skin conductance and heart rate is as high as .62 factorial weight (Thayer, 1970). Secondly, since subjects were performing the listening task at the same time, at least six (6) apparatus such as HR monitors or other instruments that provide direct physiological measures would have been necessary for use along the three days of experiments. This amount of instruments was not made available for the experiment. Also, using one or two heart rate monitors to measure six (6) subjects' physiological signals, for instance, would have consumed much time; as Rauscher et al. (1993, 1994, 1995, 1998) claim, the Mozart Effect is temporary, only lasting for around 15 minutes after exposure to auditory stimulus. Therefore, using an instrument that would be time-consuming would be counterproductive in terms of investigating the hypotheses raised for the present study.

As far as the SAM (Bradley & Leng, 1994, p. 49) concerns, this instrument "directly measures the pleasure, arousal and dominance associated with a person's affective reaction to a wide variety of stimuli", such as reaction to pictures, sounds, painful stimuli, advertisements, among many others. In the case of arousal measure, the SAM (Bradley & Lang., 1994) comprises a 9-point rating scale that varies from 1 ("completely non-aroused") to 9 ("completely aroused"), in which graphic depiction (in other words, drawn pictures) is associated to each point of the rating scale, as Figure **2.5** shows. Finally, studies carried out by Greenwald, Cook and Lang (1989) and Lang, Greenwald, Bradley, Hamm (1993) found a high correlation between the self-report arousal measures with cardiac and electrodermal responses, suggesting that the SAM is a reliable method to measure subjects' arousal levels.

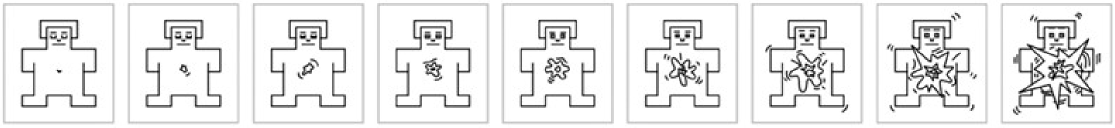


Figure 2.5: Graphic depiction of the rating scale of the arousal dimension measured by the SAM. The image on the far left corresponds to number 1 (“completely non-aroused”) of the scale, and the image on the far right corresponds to number 9 (“completely aroused”).

In order to assess subjects’ mood, this study employed the POMS adapted to European Portuguese (Viana et al., 2001). This instrument consists of 36 adjectives assigned to 6 different subscales, such as:

1) Tension-Anxiety, which comprises adjectives such as *tense, calm, nervous, impatient, anxious* and *unquiet.*
2) Depression-Dejection, which comprises adjectives such as *sad, unworthy, discouraged, lonely, downhearted, and gloomy.*
3) Hostility-Anger, which comprises adjectives such as *angry, annoyed, bad-tempered, bitter, furious* and *irritated.*
4) Fatigue- Inertia, comprising adjectives such as *exhausted, sleepy, tired, worn-out, weary and bushed.*
5) Vigor-Activity, comprising adjectives related to subjects’ levels of arousal, such as *lively, active, energetic, full of pep, alert* and *vigorous*.
6) Confusion-Disorientation: *confused, mixed-up, muddled, uncertain, competent* and *effective*

As mentioned, all these adjectives were presented to subjects in European Portuguese, as translated and validated by Viana et al. (2001). According to the authors, the factorial structure and internal consistency of the subscales are satisfactory. The internal reliability of subscales are high (Cronsbach Alpha = .75 for Tension-Anxiety, .88 for Depression-Dejection, .85 for Hostility-Anger, .91 for Fatigue-Inertia, .88 for Vigor-Activity, and .72 for Confusion-Disorientation). Also, as McNair et al. (1992) argue, these subscales are correlated with similar measures from other instruments. For instance, the Depression-Dejection subscale is highly correlated with the Beck Depression Inventory (Beck, 1978). Subjects had to rate each one of the 36 adjectives on a scale from 0 (“nothing”) to 4 (“very much”) in accordance to their affective state at a given moment, yielding a score from 6 to 30 for each subscale.

After filling in the SAM and the POMS, subjects were asked to sit comfortably on chairs placed around a round table, and the JBL Xtreme Black 2.0 was placed in the centre of the table. Subjects then listened to the auditory stimulus correspondent to their group in a given day, in accordance with Table **2.1.** As mentioned in the section regarding selection of auditory stimuli, both Metric Simple Music and Metric Complex Music were 08:25 long. Therefore, subjects were asked to remain in silence and refrain to move while they listened to the auditory stimulus. Also, experimenter asked subjects to pay attention to the rhythm of the musical piece, as they would have to answer to a question related to it after the listening task. When assigned to the Silence condition, subjects had to remain in silence for the same length as the musical stimuli.

Having performed the listening task, subjects were asked to fill in the SAM and the POMS again. At this time, however, the SAM also included the measure of the valence dimension (**Appendix VII**), in order to measure the enjoyment of each auditory stimulus. This instrument is similar to the SAM that measured subjects' arousal levels described earlier in this section, since it also comprises a scale from 1 to 9 in which graphic depiction is associated to each point of the rating scale (Figure **2.6**). Nevertheless, 1 indicated that subjects rated the stimulus "extremely unpleasant" and 9 indicated that subjects found the stimulus "extremely pleasant". Also, each drawn picture that corresponded to each number of the scale differed from the pictures used in the SAM for arousal ratings.

Finally, in line with Grahn and Rowe's (2013) study, after listening to any of the musical stimuli, subjects rated the subjective difficulty in following the beats of the musical piece throughout the listening task. As such, on a Likert-Scale from 1 ("very difficult") to 9 ("very easy"), subjects had to place an "x' on the point of the scale that represented how difficult it was to follow the musical beats. In line with the research question of the present study and the hypotheses in which the rhythmic complexity of the stimulus would play a role in the performance at MR of bodily-related pictures, the employment of this scale aim to investigate 1) whether subjects' perception of the rhythmic sequences differed between stimuli, and 2) whether subjects' perception of the rhythmic sequences was correlated with increase/decrease of performance at MR of bodily-related pictures.

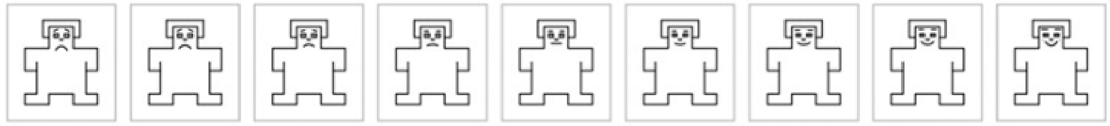


Figure 2.6: Graphic depiction of the rating scale of the valence of the stimulus measured by the SAM. The image on the far left corresponds to number 1 ("extremely unpleasant") of the scale, and the image on the far right corresponds to number 9 ("extremely pleasant").

After these procedures, each subject was then allocated to a computer to perform the MR of bodily-related pictures. Before commencing the task, experimenter asked subjects not to move their bodies during the MR task (apart from their fingers when they provided a response, obviously), and to strictly look at the computer screen while performing the task. Subjects were asked to remain in silence during the task.

Apart from these preliminary instructions, experimenter explained that a few messages would appear on the screen before subjects started the task. When subjects logged in, a welcome message popped up on the screen with instructions similar to the ones provided by the experimenter before commencing the task. Subjects had to press the SPACE BAR in order to advance to the following message. Followed to that message, another message with more specific instructions appeared on the screen. These instructions referred to the task itself. Subjects were going to see pictures of hands and feet oriented in diverse degrees of inclination. They had to press the keyboard button LEFT ARROW (←) for stimuli they judged to belong to the left-hand side of the body (left hands and left feet) or RIGHT ARROW (→), for stimuli they judged to belong to the right-side of the body (right hands and right feet). Also, subjects were told they would have limited time to respond to all trials. In fact, since the Mozart Effect predicts that the effect is temporary, lasting no longer than 15 minutes after subjects were exposed to the musical stimulus (Rauscher et al., 1993), subjects were given 15 minutes to finish the task. All subjects finished the task in time across the three days of experiment. After that message displayed on the screen, another briefing message appeared on the screen, informing subjects that they would then commence the practice trial once they pressed the SPACE BAR. Once pressed the SPACE BAR, subjects started the practice trial (**Appendix IV**). When practice trial was over, another message appeared informing that the practice trial had been done successfully and the critical trials (**Appendix III**) would begin once subjects pressed the SPACE BAR if they wished to continue with the experiment. Otherwise, they could drop out of the experiment. After performing the critical trials, a “thanks” and “goodbye” message appeared on the screen. On the first two days of experiment, subjects were released from the room after having finished the MR of bodily-related pictures tasks. On the third and last day, however, after completion of MR of bodily-related pictures, subjects were asked by the experimenter to provide their impressions and feedback about the experiment.

III. Results

1 Statistical analysis

1.1 Dependent and independent variables

Firstly, statistical analysis aims to verify the effects of the independent variables over the dependent variables (Petrica, 2003). For this study, the main independent variables, those manipulated by the experimenter, are the auditory stimuli (Metric Simple Music, Metric Complex Music, and Silence) and the degrees of inclination of the limbs displayed on the computer screen (0º, 30º, 60º, 90º, 120º, 150º and 180º). The dependent variables (those that will be measured and will measure the effect of the independent variables) will be the RTs and ACC levels of MR of bodily-related pictures. In other words, the statistical analysis will take into consideration the effects of the auditory stimuli in performance at MR of bodily-related pictures in order to investigate whether the Mozart Effect is replicated in the present study; additionally, the degrees of inclination of the limbs depicted on the screen target hypothesis **3)** described in the objectives and hypotheses section of the present study, which investigates whether structural features of the body constrain performance, on the basis that subjects employ motor imagery strategies (simulation of bodily movements in a 1PP) to carry out the task and how the biomechanical constraints of their own bodies reflect on performance. Although the selected pictures of bodily-related parts may give rise to other independent variables that could also be investigated (e.g. palm x back of the limbs, left x right limbs, hands x feet), the present study will focus on the degrees of inclination of the limbs displayed on the screen, since it relates to hypothesis **3)** in more depth than other variables that may arise from the features of the bodily-related pictures.

In line with hypothesis **2)** of the present study, which predicts that the Mozart Effect is not due to increases in arousal/mood levels or an artifact of subjects' preferences for a particular stimulus, the effect of the independent variables (in this case, the auditory stimuli only) over dependent variables other than the RTs and ACC levels in MR of bodily-related pictures was measured. More specifically, these dependent variables are the differences in scores that subjects had at the SAM for arousal before and after they were exposed to the auditory stimuli, differences in scores at the POMS before and after exposure to musical pieces or Silence, and the differences in SAM scores for valence between all stimuli after the listening task.

Finally, since the subjective perception of the difficulty in following the beats across both musical stimuli was measured through a 9-point Likert-Scale, subjects' beat perception can also be characterized as a dependent variable that aims to measure the extent to which subjects managed to perceive a particular feature of both stimuli used as an independent variable in the present study, namely the beats of the Metric Simple and Metric Complex musical pieces.

1.2 Data distribution

Data were analyzed through IBM SPSS 2.5 for Windows. Descriptive statistics (Mean values and Standard Deviation) were calculated for every variable being studied. The interpretation of statistical tests used a significance level of α=0.05 and a 95% confidence interval (Silva, 2017).

In order to verify the normality of data distribution, the Kolmogorov-Smirnov test for RTs and ACC levels yielded by subjects' performance at MR of bodily-related pictures after exposure to all three stimuli was applied. As Table **3.1** shows, RTs for MR of bodily-related pictures after subjects listened to both musical conditions yielded a low p-value, such as D(36) = 0.167, *p.* = 0.032 for Metric Simple Music, and D(36) = 0.219, *p.* = 0.001 for Metric Complex Music, meaning that a large data deviation within these variables in the population recruited for the study. Likewise, a large deviation within these variables in the population was also found for the ACC levels of MR of bodily-related pictures after subjects listened to the Metric Complex stimulus – D(36) = 0.204, *p.* = 0.003 (Table **3.2**). Thus, since some of the data from RTs and ACC levels after subjects listened to the musical stimuli do not meet with parametric assumptions, non-parametric tests, such as the Friedman Test and the Wilcoxon matched pairs test were subsequently used in order to verify the effect of the independent variables over the dependent variables.

Kolmogorov-Smirnov test of normality

	Statistic	DF	Sig.
Silence RT	0.138	36	0.151
Metric Simple RT	0.167	36	0.032
Metric Complex RT	0.219	36	0.001

Table 3.1: Kolmogorov-Smirnov test for data distribution of RTs in MR of bodily-related pictures after subjects were exposed to the three auditory stimuli.

Kolmogorov-Smirnov test of normality

	Statistic	DF	Sig.
Silence ACC levels	0.140	36	0.151
Metric Simple ACC levels	0.134	36	0.182
Metric Complex ACC levels	0.204	36	0.001

Table 3.2: Kolmogorov-Smirnov test for data distribution of ACC levels in MR of bodily-related pictures after subjects were exposed to the three auditory stimuli.

The Kolmogorov-Smirnov test for data distribution was also applied to verify whether data distribution was normal or not normal for all other variables investigated in this study, such as differences in arousal levels before and after subjects listened to any stimuli (Table **3.3**), differences in mood levels before and after subjects listened to any stimuli (Table **3.4**), valence ratings only after subjects listened to any stimulus (Table **3.5**), and ratings of beat perception after subjects listened to Metric Complex Music or Metric Simple Music (Table **3.6**) showing that data distribution did not meet with parametric assumptions; hence, non-parametric tests were also employed for their respective statistical analyses.

Kolmogorov-Smirnov test of normality for SAM ratings

	Statistic	DF	Sig.
Before Silence	0.194	36	0.005
After Silence	0.171	36	0.025
Before Metric Simple	0.153	36	0.075
After Metric Simple	0.222	36	0.001
Before Metric Complex	0.237	36	0.000
After Metric Complex	0.138	36	0.151

Table 3.3: Kolmogorov-Smirnov test for data distribution of SAM ratings for arousal levels before and after subjects were exposed to the three auditory stimuli.

Kolmogorov-Smirnov test of normality for POMS scores

	Statistic	DF	Sig.
Before Silence	0.114	36	0.200
After Silence	0.102	36	0.200
Before Metric Simple	0.198	36	0.004
After Metric Simple	0.149	36	0.086
Before Metric Complex	0.121	36	0.200
After Metric Complex	0.091	36	0.200

Table 3.4: Kolmogorov-Smirnov test for data distribution of POMS scores before and after subjects were exposed to the three auditory stimuli.

Kolmogorov-Smirnov test of normality for Valence ratings

	Statisfic	DF	Sig.
Valence for Silence	0.163	36	0.040
Valence for Metric Simple	0.195	36	0.005
Valence for Metric Complex	0.149	36	0.090

Table 3.5: Kolmogorov-Smirnov test for data distribution of SAM for ratings of stimulus valence after subjects were exposed to the three auditory stimuli.

Kolmogorov-Smirnov test for beat perception ratings

	Statistic	DF	Sig.
Beat Perception Metric Simple	0.205	36	0.002
Beat perception Metric Complex	0.201	36	0.003

Table 3.6: Kolmogorov-Smirnov test for data distribution of ratings of beat perception in a 9-point Likert-Scale after subjects were exposed to the Metric Simple and Metric Complex music.

2 Results of MR of bodily-related pictures

2.1 Results by sessions and auditory stimuli

Means and standard deviations for RTs and ACC levels for MR of bodily-related pictures after subjects were exposed to the three auditory conditions (Metric Simple Music, Metric Complex Music, and Silence) are provided in Tables **3.7** and **3.8**, respectively. The first analyses employed a Friedman Test in order to verify whether subjects' performance at MR of bodily-related pictures varied as a function of the session order (session 1, session 2, and session 3) and listening conditions (the three auditory stimuli).

Means (M) and Standard Deviations (SDs) of RTs in all auditory conditions

	N	M	SD
Silence RT	36	1310.13	439.86
Metric Simple RT	36	1402.31	588.29
Metric Complex RT	36	1384.22	650.14

Table 3.7: Means and Standard Deviations for RTs (in milliseconds) after subjects were exposed to silence, Metric Simple Music and Metric Complex Music, respectively.

Means (M) and Standard Deviations (SDs) of ACC levels in all auditory conditions

	N	M	SD
Silence ACC levels	36	87.10	10.90
Metric Simple ACC levels	36	85.83	09.68
Metric Complex ACC levels	36	86.80	11.97

Table 3.8: Means and Standard Deviations for ACC levels (in percentage) after subjects were exposed to Silence, Metric Simple Music and Metric Complex Music, respectively.

First, a Friedman test was performed to examine whether there was significant differences in RTs and ACC in sessions 1, 2 and 3, respectively. Statistical analysis showed significant differences across RTs in sessions 1, 2 and 3, $X^2(2, N= 36) = 32.067$, *p.* = 0.00 (Figure **3.1**). By comparing RTs of each session through Wilcoxon T-tests, it was found out a significant difference amongst the 3 possible combinations (*p.* < 0.00 in the comparison between sessions 1 and 2; *p.* < 0.00 in the comparison between sessions 1 and 3; and *p.* = 0.09 in the comparison between sessions 2 a 3), in which faster response times were produced in session 3 (M=1192.16, SD=356.86) than in session 2 (M= 1320.15, SD=518.09), than in session 1 (M=1584.76, SD=689.23), respectively. However, this improvement in performance was not reflected on the ACC levels, since the Friedman test yielded no significant differences in ACC levels for MR of bodily-related pictures across sessions 1, 2 and 3, respectively [X^2(2, N=30) = 3.297, *p.* = 0.192] (**Figure 3.2**).

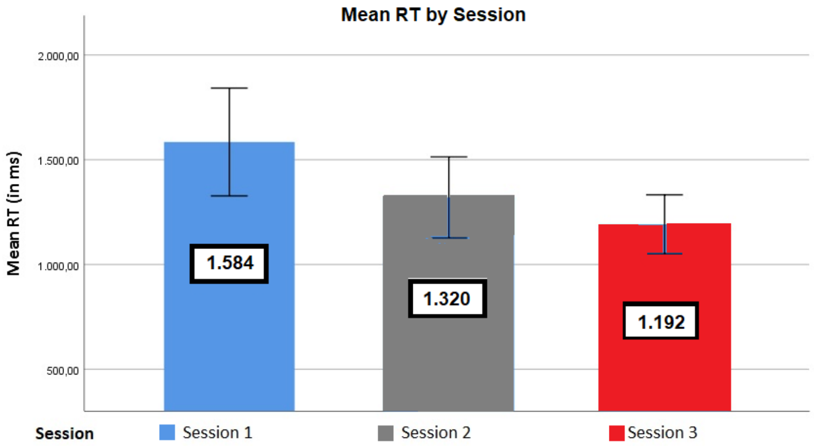


Figure 3.1: Graph with the mean RTs (in milliseconds) and SDs (error bars) yielded by subjects at MR of bodily-related pictures for each session, regardless of auditory condition.

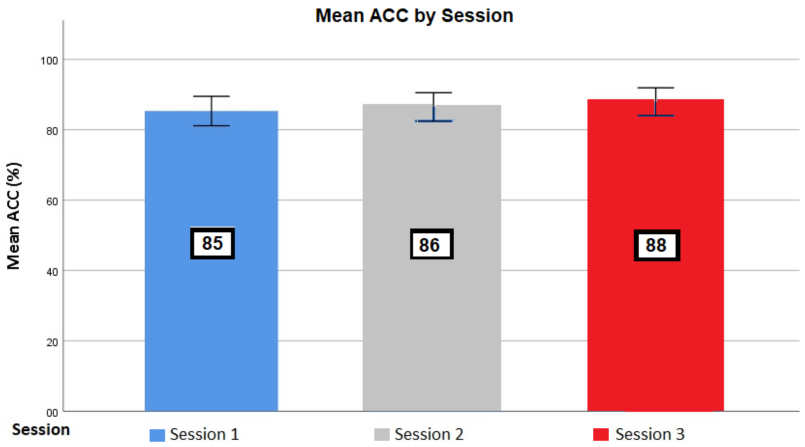


Figure 3.2: Graph with the mean ACC levels (in percentage) and SDs (bars) yielded by subjects at MR of bodily-related pictures for each session, regardless of auditory condition.

Conversely, a Friedman test yielded *no* significant differences in RTs and ACC levels for MR of bodily-related pictures after subjects were exposed to any of the three auditory stimuli, namely Metric Simple Music, Metric Complex Music, and Silence, across the three days of experiments [X^2(2, N=36) = 0.467, *p.* = 0.792 for RTs, and X^2(2, N=36) = 0.883, *p.* = 0.643 for ACC levels], as shown in Figures

3.3 and **3.4**, respectively. Taken together, these results suggest that, as expected, subjects improved their response speed at MR of bodily-related pictures along the sessions; however, this performance was *not* significantly better after subjects were exposed to any auditory stimuli. Hence, the Mozart Effect *was not* replicated in the present study.

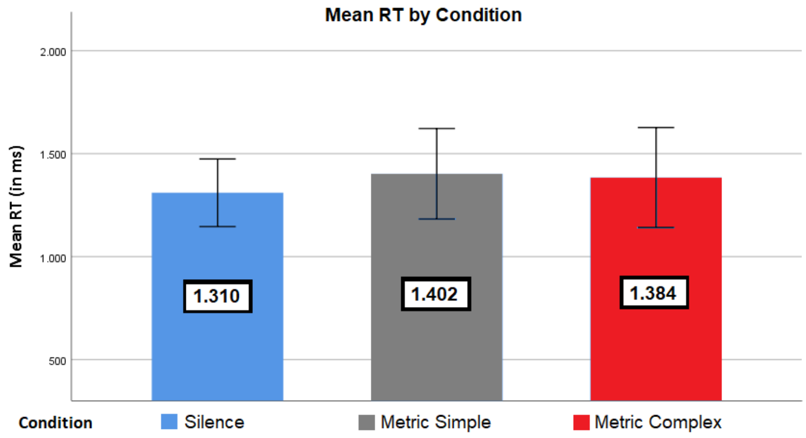


Figure 3.3: Graph with the mean RTs (in milliseconds) and SDs (error bars) yielded by subjects at MR of bodily-related pictures after exposure to all three auditory stimuli, namely Silence, Metric Simple and Metric Complex, respectively.

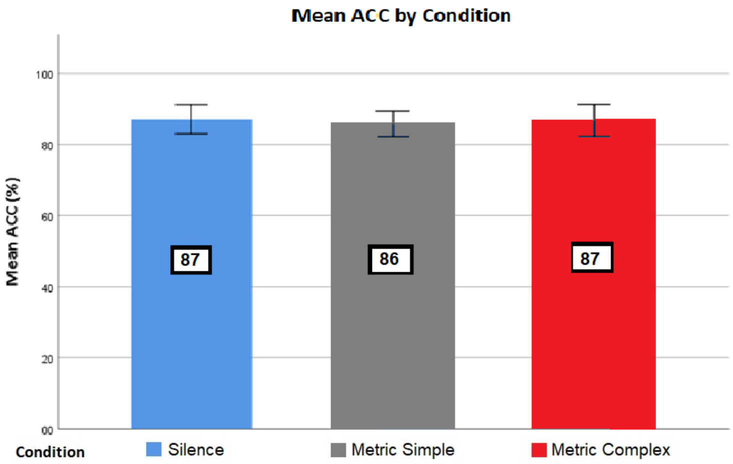


Figure 3.4: Graph with the mean ACC levels (in percentage) and SDs (bars) yielded by subjects at MR of bodily-related pictures after exposure to all three auditory stimuli, namely Silence, Metric Simple and Metric Complex, respectively.

2.2 Results by pictures' degrees of inclination

Apart from the RTs and ACC levels yielded by subjects along sessions 1, 2 and 3, and after exposure to auditory stimuli prior to the task, the response rates for bodily-related pictures displayed in different degrees of inclination (30º, 60º, 90º, 120º, 150º, 180º, inclined clockwise and anti-clockwise from 0º) were measured. Table **3.9** shows the mean and SD values of RTs and Table **3.10** corresponds to mean values and SDs for ACC levels for those pictures.

Mean (M) and Standard Deviations (SDs) for RTs in degrees of rotation, clockwise and anticlockwise

	N	M	SD
180º	36	1618.56	714.39
150º Anti-clockwise	36	1480.08	572.66
120º Anti-clockwise	36	1370.01	619.01
90º Anti-clockwise	36	1385.03	570.19
60º Anti-clockwise	36	1313.96	522.51
30º Anti-clockwise	36	1243.76	421.13
0º	36	1241.86	428.01
30º Clockwise	36	1242.58	485.04
60º Clockwise	36	1297.62	480.22
90º Clockwise	36	1349.22	591.88
120º Clockwise	36	1444.36	557.01
150º Clockwise	36	1554.57	643.57

Table 3.9: Means and Standard Deviations for RTs (in ms) for pictures in all degrees of inclination, rotated both clockwise and anti-clockwise from canonical position.

Mean (M) and Standard Deviations (SDs) for RTs in degrees of rotation, clockwise and anticlockwise

	N	M	SD
180º	36	80.67	11.84
150º Anti-clockwise	36	82.13	13.55
120º Anti-clockwise	36	84.57	12.13
90º Anti-clockwise	36	87.27	13.36
60º Anti-clockwise	36	89.53	11.06
30º Anti-clockwise	36	88.40	13.67
0º	36	89.97	12.26
30º Clockwise	36	87.67	12.67
60º Clockwise	36	89.63	09.84
90º Clockwise	36	89.70	11.40
120º Clockwise	36	84.50	11.96
150º Clockwise	36	80.17	12.98

Table 3.10: Means and Standard Deviations for ACC levels (in percentages) for pictures in all degrees of inclination, rotated both clockwise and anti-clockwise from canonical position (0º).

A Friedman test yielded significant differences for both RTs and ACC levels for pictures displayed in different degrees of inclination [$X^2(11, N=36) = 120.59$, *p.* < 0.00 for RTs, and $X^2(11, N=36) =$

68.188, $p. < 0.00$ for ACC levels] as Figures **3.5** and **3.6** show, respectively. By comparing the side at which pictures were rotated departing from the canonical position (0º), no significant differences were found for pictures displayed anticlockwise from the canonical position to their counterparts displayed at the clockwise from the canonical position [$X^2(2, N=36) = -0.195$, $p. = 0.845$ for RTs, and $X^2(2, N=36) = -0.054$, $p. = 0.957$ for ACC levels]. The lack of significant differences was also observed for RTs and ACC levels for side of the limbs (right hands/feet x left hands/feet) depicted on the screen [$X^2(2, N=36) = -1758.00$, $p. = 0.079$ for RTs, and $X^2(2, N=36) = -0.34$, $p. = 0.973$ for ACC levels].

By comparing RTs between pictures depicted at each degree of inclination through Wilcoxon t-tests, it was found out that pictures in 0º received significantly faster responses than pictures displayed in 60º ($z = -2.005$, $p. = 0.04$), 90º ($z = - 2.376$, $p. = 0.01$), 120º ($z = 2.972$, $p. < 0.00$), 150º ($z = -4.453$, $p. < 0.00$), and 180º ($z = -4.53$, $p. < 0.00$), respectively. Pictures displayed at 30º anti-clockwise and clockwise had significantly faster responses than pictures displayed in 60º ($z = -2.952$, $p. = 0.003$), 90º ($z = -3.222$, $p. < 0.00$), 120º ($z = -3.651$, $p. < 0.00$), 150º ($z = -4.721$, $p. < 0.00$), and 180º ($z = -4.78$, $p. < 0.00$), respectively. Concomitantly, significant differences were found for RTs depicted in 60º compared to those at 90º ($z = -2.026$, $p. = 0.04$), 120º ($z = -2.705$, $p. = 0.007$), 150º ($z = 4.576$, $p. = 0.00$) and 180º ($z = -4.247$, $p. <0.000$). Finally, pictures displayed at 90º differed in RTs compared to pictures displayed at 150º and 180º ($z = - 3.918$, $p. < 0.00$ for 150º, and $z = -3.569$, $p. < 0.00$ for 180º) and pictures displayed at 120º also differed from those depicted at 150º and 180º ($z = -4.309$, $p. < 0.00$ for 150º, and $z = -4.021$, $p. < 0.00$ for 180º). No significant differences were found in RTs between pictures displayed at 0º and 30º ($z= -1.162$, $p. = 0.245$), 90º and 120º ($z = -0.36$, $p. = 0.719$), and 150º x 180º ($z= -0.895$, $p. = 0.371$).

Differences in ACC levels were less significant than differences in RTs between pictures displayed in different degrees of inclination. ACC levels for pictures displayed at 0º differed significantly from those displayed at 150º and 180º, respectively ($z = -4.227$, $p. = 0.00$ for 150º, and $z = -3.303$, $p. = 0.001$ for 180º). The same pattern emerged for other pictures, such as those displayed at 30º, 60º, 90º and 120º, respectively, in which ACC levels for all of them differed significantly from ACC levels of pictures displayed at 150º and 180º. Pictures at 30º x 150º yielded $z = -3.706$, $p. < 0.00$, and pictures at 30º x 180º yielded $z = -3.104$, $p. = 0.002$. Concomitantly, comparing pictures displayed at 60º with those at 150º and 180º yielded $z = -4.226$, $p. = 0.010$, and $z = -3.254$, $p. = 0.001$, respectively. The comparison between pictures displayed at 90º and those at 150º and 180º, respectively, yielded $z = -4.031$, $p. < 0.000$, and $z = -2.578$, $p. = 0.010$. Finally, pictures displayed at 120º yielded significant differences in terms of ACC levels compared to those displayed at 150º ($z = -3.342$, $p. < 0.00$) and 180º ($z = -2.467$, $p. = 0.014$), respectively.

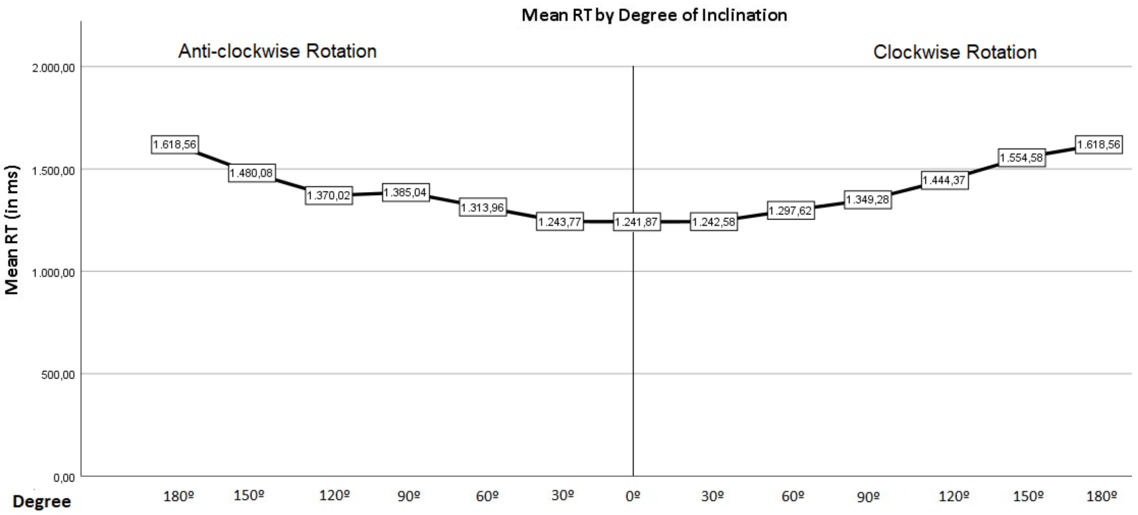


Figure 3.5: Graph depicting mean RTs (in milliseconds) for pictures displayed at different degrees of inclination (30º, 60º, 90º, 120º, 150º, and 180), rotated both clockwise and anti-clockwise from canonical position (0º).

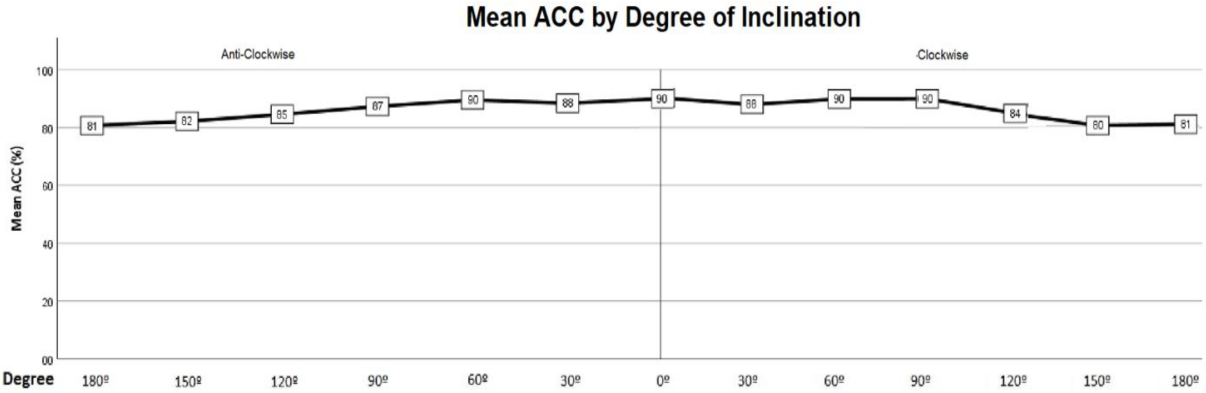


Figure 3.6: Graph depicting mean ACC levels (in percentage) for pictures displayed at different degrees of inclination (30º, 60º, 90º, 120º, 150º, and 180), rotated both clockwise and anti-clockwise from canonical position (0º).

Finally, by carrying out an analysis of variance to compare subjects' performance for all seven degrees of inclination (0º, 30º, 60º, 90º, 120º, 150º and 180º) conveyed by the pictures and the three auditory conditions (Metric Simple, Metric Complex, and Silence) it was observed that subjects' RTs and ACC levels for pictures displayed at different degrees of inclination *did not* differ significantly after subjects were exposed to any auditory stimulus. Pictures depicted at 0º yielded $X^2(2, N=36) = 4.267$, *p*. = 0.118 for RTs, and $X^2(2, N=36) = 2.656$, *p*. = 0.265 for ACC levels in the comparison between all three auditory stimuli. Pictures at 30º yielded $X^2(2, N=36) = 0.267$, *p*. = 0.875 for RTs, and $X^2(2, N=36) =$

2.731, *p.* = 0.875 for ACC levels across auditory stimuli. RTs for pictures at 60º yielded X^2(2, N=36) = 0.800, *p.* = 0.670, and ACC levels yielded X^2(2, N=36) = 0.800, *p.* = 0.670. Pictures depicted at 90º yielded X^2(2, N=36) = 0.267, *p.* = 0.875, and X^2(2, N=36) = 4.795, *p.* = 0.091 for RTs and ACC levels across stimuli exposure, respectively. For pictures displayed at 120º, X^2(2, N=36) = 0.487, *p.* = 0.792 was yielded for RTs, and X^2(2, N=36) = 3.493, *p.* = 0.174 for ACC levels across all auditory stimuli. Pictures at 150º yielded X^2(2, N=36) = 2.067, *p.* = 0.356 for RTs and X^2(2, N=36) = 0.257, *p.* = 0.879 for ACC levels. Finally, pictures depicted at 180º yielded X^2(2, N=36) = 0.467, *p.* = 0.792 for RTs, and X^2(2, N=36) = 0.212, *p.* = 0.900 for ACC levels after subjects were exposed to all auditory stimuli.

3 Arousal, mood, valence and beat perception

In order to verify whether a possible Mozart Effect would be due to increases in arousal and mood levels (Husain et al., 2002), subjects' arousal and mood levels were measured before and after they were exposed to auditory stimuli prior to completion of MR of bodily-related pictures. First, Table **3.11** depicts the mean Values and SDs for subjects' arousal levels before and after exposure to all three auditory stimuli, according to subjects' self-reports on the SAM (Bradley & Leng, 1994), as described in the procedures section of the present study.

Means (M) and Standard Deviations (SDs) for subjects' arousal levels before and after exposure to auditory stimuli

	N	M	SD
Before Silence	36	4.70	1.96
After Silence	36	3.97	1.92
Before Metric Simple	36	4.73	1.85
After Metric Simple	36	4.30	1.87
Before Metric Complex	36	5.23	1.73
After Metric Complex	36	4.30	1.72

Table 3.11: Means and Standard Deviations for SAM ratings for arousal levels before and after exposure to auditory stimuli.

Since the variable in interest is the variance of subjects' self-reported arousal levels after exposure to auditory stimuli, Wilcoxon t-tests were employed in order to verify if subjects' response to the SAM changed between before and after exposure to each stimulus. Thus, statistical analyses were carried out separately for each auditory stimulus.

First, significant differences were found for the variance in self-reported arousal levels after subjects remained in Silence (*z* = -2.381, *p.* = 0.017) and listened to Metric Complex Music (*z* = - 2.325, *p.* = 0.020). More specifically, these results suggest that subjects' self-reported arousal levels *decreased* after they were exposed to both Silence and Metric Complex Music. Conversely, no significant differences were found for the variance in subjects' self-reported arousal levels after they were exposed to Metric Simple Music (z = - 1.817, *p.* = 0.069). Figure **3.7** depicts the differences found in the variances between subjects' self-reported arousal levels after exposure to all three auditory stimuli.

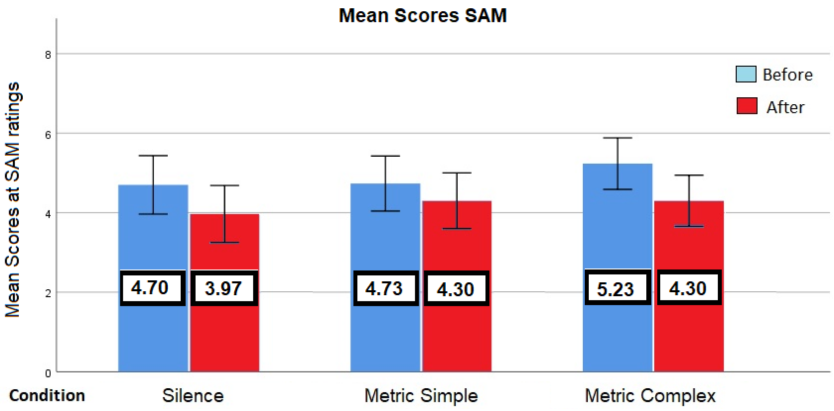
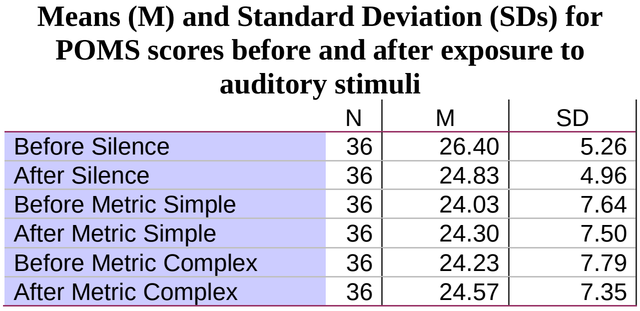


Figure 3.7: Graph depicting the differences in mean ratings and SDs (error bars) of subjects' self-reported arousal levels between before and after they were exposed to each auditory stimulus

A similar analysis was carried out to compare subjects' mood levels before and after exposure to auditory stimuli. As described, the POMS adapted to European Portuguese (Viana et al., 2001) was administered, and similarly to the SAM (Bradley & Leng, 1994), subjects had to fill in a table with 36 adjectives that comprise six different dimensions, such as Tension-Anxiety, Depression-Dejection, Hostility-Anger, Fatigue-Inertia, Vigor-Activity, and Confusion-Disorientation. Firstly, the total scores subjects had at each one of these six dimensions were summed. Table **3.12** shows the mean Values and SDs for POMS total scores. Secondly, Wilcoxon t-tests were applied in order to verify whether significant differences for POMS total scores between before and after subjects were exposed to each auditory stimuli. Again, statistical analyses were carried out separately for each auditory stimulus.

Wilcoxon t-tests comparing POMS total scores before and after exposure to each auditory stimulus yielded significant differences for the total scores between before and after subjects remained in silence prior to task completion (z = -2.109, *p.* = 0.035). No significant differences were found for POMS total scores between before and after subjects were exposed to either Metric Simple Music or Metric Complex Music (z = -0.293, *p.* = 0.769 for Metric Simple Music, and z = -0.492, *p.* = 0.623 for Metric Complex Music). Figure **3.8** depicts the differences between POMS scores both before and after subjects were exposed to each one of the three auditory stimuli.



Means (M) and Standard Deviation (SDs) for POMS scores before and after exposure to auditory stimuli

	N	M	SD
Before Silence	36	26.40	5.26
After Silence	36	24.83	4.96
Before Metric Simple	36	24.03	7.64
After Metric Simple	36	24.30	7.50
Before Metric Complex	36	24.23	7.79
After Metric Complex	36	24.57	7.35

Table 3.12: Means and Standard Deviations for POMS scores before and after exposure to auditory stimuli.

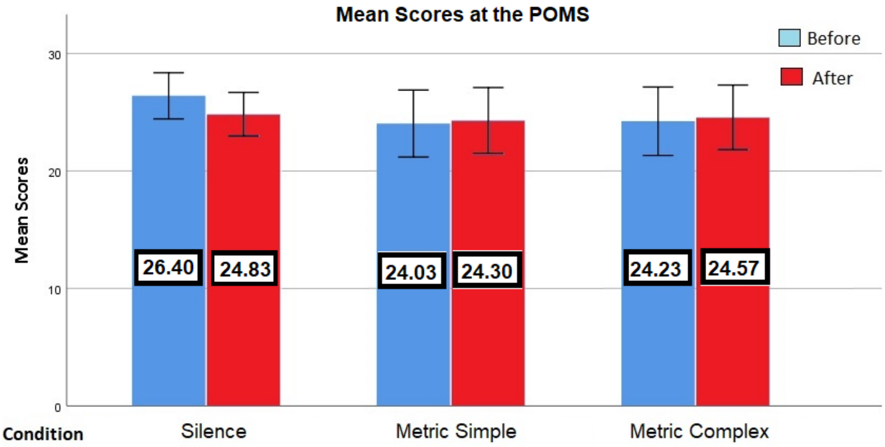
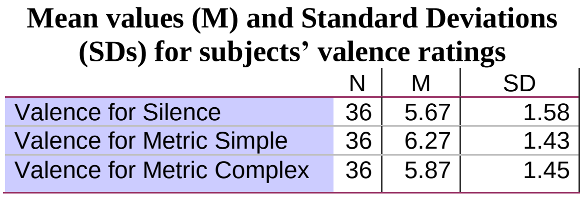


Figure 3.8: Graph depicting the differences in subjects' self-reported mood levels and SDs (error bars) between before and after they were exposed to each auditory stimulus through POMS total scores (Viana et al., 2001).

Although significant differences in total scores at the POMS after subjects remained in silence compared to before exposure to this particular stimulus were found, by investigating the differences in scores for all 6 dimensions of the POMS between before and after subjects remained in silence, significant differences only emerged for the Vigor-Activity dimension of adjectives related to mood (z = -2.908, $p.$ = 0.004). This specific dimension comprises adjectives related to how aroused subjects feel like at a given moment. In line with the results obtained through the SAM regarding the arousal levels after subjects were exposed to Silence, the scores at this particular dimension of the POMS also suggest that subjects' arousal levels decreased after they remained in silence. Interestingly, scores at the POMS for the Vigor-Activity dimension did not replicate the results obtained through the SAM after subjects were exposed to Metric Complex Music, since no significant differences in the Vigor-Activity dimension were found between before and after subjects listened to this specific stimulus (z = -0.058, $p.$ = 0.954). No significant differences were found for any other dimensions under the silent condition, nor in other conditions.

In order to verify whether subjects had preferences for any specific auditory stimulus, a SAM for valence (Bradley & Leng, 1994) was applied after subjects were exposed to each one of the auditory stimulus. Subjects were asked to rate the stimulus on a Likert-Scale from 1 to 9. Figure **3.13** shows subjects valence ratings across the auditory stimuli.

Differently from the analyses carried out for both arousal and mood levels, valence ratings were measured only after subjects were exposed to an auditory stimulus. Thus, valence ratings between all three different stimuli were compared. As a result, a Friedman test yielded no significant differences in valence ratings between Silence, Metric Simple Music and Metric Complex Music [$X^2(2, N=36) = 3.556$, *p*. = 0.169)]. Figure **3.9** depicts the differences in valence ratings across the three auditory stimuli.



Mean values (M) and Standard Deviations (SDs) for subjects' valence ratings

	N	M	SD
Valence for Silence	36	5.67	1.58
Valence for Metric Simple	36	6.27	1.43
Valence for Metric Complex	36	5.87	1.45

Table 3.13: Means and Standard Deviations for SAM ratings for valence after exposure to each auditory stimuli.

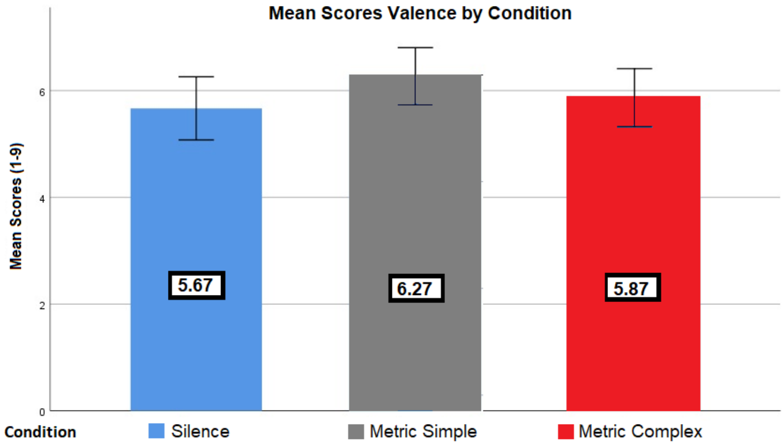


Figure 3.9: Graph depicting subjects' valence ratings and SDs (error bars) between all three different auditory stimuli.

Finally, in order to verify whether subjects managed to perceive and follow the rhythmic structures of both Metric Simple and Metric Complex Music, through a 9-point Likert-Scale, subjects had to indicate whether following the rhythmic structures of each musical stimulus was "very difficult" (in this case, subjects had to place an fill in the number 1 box with an "x"), "very easy" (by filling in the number 9 box with an "x) or any other number in the scale in-between, according to their perception.

As expected, ratings of beat perception of Metric Simple beats (M = 7.57, SD = 1.22) were significantly higher than ratings of Metric Complex Music beats (M = 6.13, SD = 1.65), as the result of a Wilcoxon t-test shows: *z* = - 3.631, *p*. < 0.000. Figure **3.10** depicts these differences.

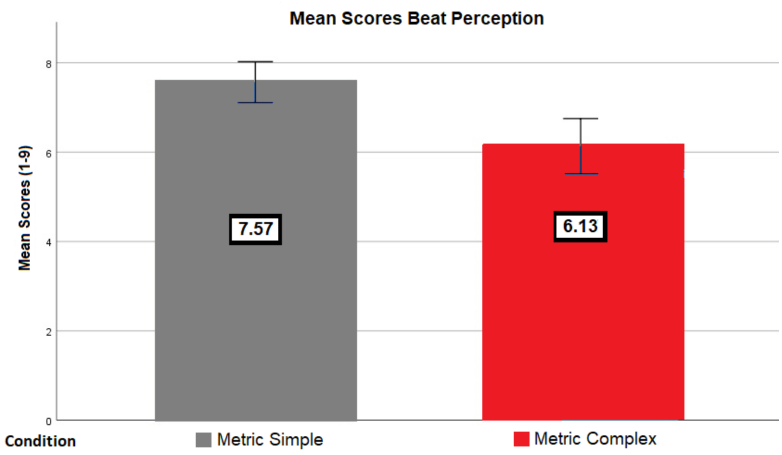


Figure 3.10: Graph depicting subjects' ratings of beat perception and SDs (error bars) between Metric Simple and Metric Complex Music through a 9-point Likert-Scale.

4 Subjects' feedback

After completion of the MR of bodily-related task in the last day of experiment, experimenter asked subjects to provide their brief feedback on the experiment. Instead of leaving the room, as in the first two days of experiment, subjects were asked to sit back on the chairs they were previously allocated during the listening task.

First of all, experimenter asked subjects whether they had employed a specific strategy to carry out the MR of bodily-related pictures and, in affirmative cases, what specific strategy had been employed. As a response, all subjects reported that they had imagined the rotation of the pictures displayed on the screen as if they were physically rotating their own limbs. Thus, subjects performed a motor simulation of their own actions (physical rotation of hands and feet) in order to accomplish the task, in line with Jeannerod's (1994, 1995, 2006) description of motor simulation and previous studies on MR of cubes (e.g. Wexler et al., 1998).

Experimenter also asked subjects whether, in order to rotate the image, they had fixated a point of reference in the picture. Most subjects responded that the thumbs (for the hands) and the toes (for the feet) were the point of references, and they rotated the image according to where these points of reference were located on the screen. Two subjects, however, responded that they had chosen a specific point at the palm (or back) of the hands to do the rotation (more specifically, below the index finger), and a point in the sole of the foot (in their own words "the salient curve" below the toe).

Subjects were also asked which pictures they found the most difficult ones to provide an answer to. This question yielded no consensus amongst subjects, since some reported having more difficulties during the practice trials (**Appendix IV**) compared to the critical trials (**Appendix III**). Most subjects, however, reported having experienced more difficulties in the laterality judgment when the pictures were depicted at 180º compared to other degrees of rotation. Finally, subjects reported having no apparent difficulties in discriminating left limbs from right limbs or in rotating pictures displayed at clockwise or anti-clockwise orientation departing from the canonical position. This verbal feedback is consistent with the data.

Finally, as far as the auditory stimuli concerns, all subjects reported having noticed differences in the rhythmic structures of the musical stimuli. This verbal feedback is consistent with the data described last section regarding subjects' beat perception. These differences, however, did not elicit any negative emotions nor any preference toward the Metric Complex Music compared to the Metric Simple Music, and vice-versa, according to subjects. Furthermore, when asked whether the exposure to the musical stimuli influenced their performance at the tasks, while some participants reported that musical stimuli made them feel relaxed and concentrated prior to the task, a few subjects reported that the musical stimuli made them feel more aroused and concentrated to the task. A few subjects, however, reported that, since the musical stimuli (a minimalist techno) were not correspondent to their favorite musical genre, exposure to musical stimuli was detrimental to the subsequent task, since they felt less concentrated for the task, according to their verbal report. These subjects reported that their performance was better after they remained in silence, rather than when they were exposed to any musical stimulus. In line with this point, most subjects reported that exposure to silence made them feel more relaxed and concentrated to task completion compared to the exposure to the musical stimuli; conversely, however, a few subjects felt anxious with the silence, and reported that the music (both Metric Simple and Metric Complex) elicited more positive feelings before completion MR task. Finally, when asked about the stimuli that they preferred the best, subjects yielded no consensus in their response. Although some had demonstrated preferences for any of the musical stimulus (without specifying which one), some had preferred the silence. The verbal report stated in this paragraph is consistent with the data regarding the valence of the stimuli yielded by the SAM (Bradley & Leng, 1994) described in the last section, and somewhat consistent with the results yielded by the SAM for arousal (Bradley & Leng, 1994) and the POMS (Viana et al. 2001) regarding arousal decrease after subjects were exposed to silence.

IV. Discussion

1 Interpretations of the results

In the light of the hypotheses raised in section 4 of the Theoretical Background chapter of the present study, the results from the experiment described in the last chapter will now be discussed.

The present investigation aimed to verify whether after listening to musical stimuli subjects would enhance their performance at MR of bodily-related pictures. Thus, in line with studies carried out by Rauscher et al. (1993, 1994, 1995, 1998), this study aimed to verify whether a Mozart Effect would emerge for this specific task and with the specific musical stimuli selected. Further, the present study specifically investigated whether manipulation of one specific musical element alone, namely, the rhythm, would suffice to increase subjects' performance at the task, in which only the rhythmic structures of the musical piece were manipulated by the experimenter, giving rise to two distinct musical stimuli that were eventually used in the experiment: Metric Simple Music and Metric Complex Music. In sum, as described in the objectives and hypotheses section of the present study, some assumptions were raised in order to derive the hypotheses that were going to be investigated through the experiment. Those assumptions were based on empirical findings and theoretical assumptions encountered in the ECT, motor imagery, music perception and Mozart Effect literature. Those assumptions are:

(I) Weak embodiment: *some* concepts are the simulations of perceptual, motor and introspective experiences, grounded in modality-specific systems of the brain (Mahon, 2015).

(II) Motor imagery is the simulation of bodily movements, carried out in modality-specific systems of the brain, namely, the motor cortices (Jeannerod, 2006).

(III) MR tasks of bodily-related pictures are accomplished by means of simulation of one's own bodily movements to accomplish the task (Wexler et al., 1998).

(IV) Music activates the motor cortices of the brain, and this activation varies in degree according to the rhythmic complexity of the auditory stimulus, in which metric simple rhythmic structures elicit higher neuronal activation in these brain areas than metric complex and non-metric rhythmic structures (Grahn & Brett, 2007).

(V) Increase of cortical activation and synchronization of neural pattern activities in specific brain areas used for cognitive tasks after music listening results in performance enhancement at the task compared to control conditions and other stimuli (Rauscher et al., 1993).

(VI) Increase of cortical activation and synchronization of neural pattern activities in specific brain areas used for cognitive tasks after music listening are the reason why the Mozart Effect is possible, and not subjects' increase of arousal/mood levels or subjects' preference for a stimulus (Rauscher et al, 1995; Bodner et al., 2001).

Based on these assumptions, hypothesis **1)** predicted that after listening to Metric Simple Music, subjects would have better performance at MR of bodily-related pictures compared to Metric Complex Music and Silence. As data reported in the Results chapter of the present study suggest, this hypothesis was *not* confirmed, since performance levels did not differ after subjects listened to Metric Simple Music, Metric Complex Music or Silence before carrying out the MR of bodily-related parts. This lack of confirmation relates to the research question raised in the objectives and hypothesis section, namely, ***does listening to music enhance performance at MR of bodily-related pictures?*** Accordingly, based on data, the answer for this question would be a *no*. In this case, since there was no performance enhancement at MR of bodily-related pictures after subjects were exposed to the stimuli, hypothesis **2)** raised in the objectives and hypothesis section, which stated that subjects would have had a better performance after listening to Metric Simple Music compared to the other two stimuli, and that performance enhancement would be due to increase in cortical activation of modality-specific areas involved in the MR task elicited by the Metric Simple Music, and not to any significant increase in arousal/mood levels or as an artifact of preference for any particular stimulus (Chabris, 1999), would also receive a *no* as an answer in the present study, since there were no significant differences in performance after subjects were exposed to any of the three stimuli. Likewise, in line with hypothesis **2)**, question **C)** raised in the objectives and hypotheses section (if there are significant differences in performance after subjects listened to distinct auditory stimuli, are these differences due to brain activation elicited by the music or changes in arousal/mood levels or preference for a given stimulus?) would remain unaddressed in the present study, since no enhancement in performance after exposure to any stimulus was observed.

In line with the lack of confirmation of hypotheses **1)** and **2)**, it is hypothesized that at least one or more than one assumption (**I-VI)** described above are false. Notwithstanding, it is important to note that, since the present study did not employ any brain-mapping techniques, such as fMRI, EEG, etc., some of the possible explanations of why hypotheses **1)** and **2)** were not observed in the present study may be speculative, since it was not possible to observe which brain areas were activated either during the pre-intervention phase (auditory listening) nor the performance of MR of bodily-related tasks.

As an example of speculative hypothesis that would account for the null result observed in the experiment regarding hypothesis **1)** and **2)**, it is possible to hypothesize that assumption **I** - Weak embodiment: *some* concepts are the simulations of perceptual, motor and introspective experiences, grounded in modality-specific systems of the brain (Mahon, 2015) - may be *false* for motor concepts used in motor imagery tasks. As described in the objectives and hypotheses section, it was expected that musical stimuli selected for this study would elicit activation in the motor cortices, modality-specific areas involved in motor imagery (**II**) and in MR tasks of bodily-related pictures (**III**). This activation would enhance subjects' performance in posterior tasks, which was not observed, according to data. According to conceptual embodiment (Mahon, 2015), all concepts are grounded in modality-specific areas of the brain (strong embodiment) or some concepts are grounded in modality-specific areas of the brain (weak embodiment), and concepts are simulations of perceptual, motor and introspective experiences (Barsalou, 1999). This particular study investigated whether some concepts (motor concepts used in motor imagery) are grounded in modality-specific brain areas, hence, weak embodiment. Since the prediction from hypotheses **1)** and **2)** was not confirmed by the data, it could be the case that motor concepts used in motor imagery tasks may *not* be grounded in modality-specific areas of the brain. It could be the case that, for instance, musical stimuli have stimulated the motor cortices, but this stimulation would not have made any difference for performance, since motor concepts involved in motor imagery tasks may not be grounded in the modality-specific areas such as the motor cortices. Once again, since this study did not employ, for instance, EEG or fMRI methods to observe which parts of the brain were activated, the hypothesis that musical stimuli activated the motor cortices but motor concepts used in motor imagery tasks are not grounded in modality-specific areas, such as the motor cortices, is speculative. However, if this speculative hypothesis is true and motor concepts are not grounded in modality-specific areas of the brain, then question **A)** (are motor concepts used in motor imagery tasks grounded in modality-specific systems?) is addressed, and the answer for that question would then be negative.

Conversely, if there had been a Mozart Effect and listening to music had enhanced subjects' subsequent performance at MR of bodily-related pictures, this result would have suggested that weak embodiment is true for, at least, motor concepts. The reasoning is similar to the one stated in the last paragraph hypothesizing that weak embodiment may be false for motor concepts. However, in this case, if there had been a Mozart Effect, it could be the case that motor cortices involved in MR of bodily-related pictures would have been activated, facilitating performance. This result would have provided weak conceptual embodiment with some evidence, since it would suggest that motor concepts used in motor imagery tasks are grounded in modality-specific systems that were activated by the music and facilitated performance at the MR of bodily-related pictures.

Further, the hypothesis that weak conceptual embodiment may be false would reflect on some other assumptions, such as **II** and **III.** First, weak embodiment may not be true for motor imagery tasks, since motor concepts may not be grounded in modality-specific brain systems, such as the motor cortices. Assumption **II** claims that motor imagery is the simulation of bodily movements, carried out in modality-specific systems of the brain, namely, the motor cortices (Jeannerod, 2006). This assumption can be further divided in two claims: [1] motor imagery is the simulation of bodily movements, and [2] motor imagery is grounded in modality-specific systems of the brain. According to subjects' self report after the experiment, all subjects reported having imagined performing the task by taking their own body as perspective in order to rotate the limbs depicted on the screen, imagining the limbs depicted being rotated as if they were physically rotating their own body parts. Thus, subjects carried out the rotation of the limbs on the picture through a 1PP, not a 3PP person perspective. This is consistent with motor imagery, since in motor imagery, subjects usually imagine themselves carrying a motor action through the 1PP (Jeannerod, 1995). Thus, if motor imagery is the simulation of bodily movements performed through 1PP and subjects carried out the MR of bodily-related pictures through a 1PP, then claim number [1] stated in this paragraph is addressed. However, according to the hypothesis that weak embodiment for motor concepts may be false, it seems like claim number [2] stated in this paragraph may not hold true. More specifically, one thing is to suggest that subjects performed the task by means of simulations of bodily movements (**III**), which accounts for claim number [1] raised in this paragraph; another thing is to claim that this simulation are grounded in modality-specific areas in the brain (claim number [2] of this paragraph). If a similar reasoning applied to the hypothesis that weak conceptual embodiment may be false for motor concepts were to be applied to motor imagery, then music that would have activated the motor cortices would not have made any difference for performance, since simulation of bodily movements may not take place in modality-specific regions. In this sense, it could be the case that simulations of bodily movements are carried out through manipulation of abstract, amodal symbols in a language of thought, consistent with CCTM, not necessarily taking place in modality-specific areas of the brain. Likewise, this hypothesis would also relate to assumption **III,** since MR of bodily-related pictures could have been performed through simulation of bodily movements, but not specifically using modality-specific areas of the brain either, namely the motor cortices.

The hypothesis that weak conceptual embodiment may be false for motor concepts on the grounds that motor concepts may not be grounded in modality-specific areas of the brain may also reflect on the constraining and constitutive role that the non-neural parts of the body may have in cognition, as entailed by conceptual embodiment. First, as stated in section 1.3 of the present study, conceptual embodiment can be seen as a form of ECT, since structural features of the body play a constitutive and constraining role in the concepts we use in motor imagery, in this case, the motor concepts. More specifically, since concepts are simulations and simulations are the "reenactment of perceptual, motor, and introspective states acquired during experience with the world, body and mind", hence, bodily experiences in an environment play a constitutive role in simulations (Barsalou, 2008, p. 618). If weak conceptual embodiment for motor concepts is not true, then it may be the case that motor concepts may not be the simulations of past experiences grounded in modality-specific brain areas. Again, it could be the case that, for instance, motor concepts are deployed through the manipulation of abstract, amodal symbols in a language of thought, as discussed in section 1.1 of this study. Likewise, if weak conceptual embodiment for motor concepts is not true and concepts are not the simulations of past experiences, then the non-neural parts of the body may not play a constraining role in the motor concepts deployed in motor imagery tasks. If body as a constraint hypotheses is false on the grounds that weak conceptual embodiment for motor concepts is false, then question **B)** would be addressed with 'no' as a response.

Although the hypothesis that weak conceptual embodiment for motor concepts may not be true reflects on constitutive and constraining roles of the body on cognition, this specific hypothesis does not entail that ECT is not true. As described in section 1.2.1 of the theoretical background in the present study, the ECT entails that the body can play a physical constitutive role or a constraining role in cognition, and this is regardless of whether conceptual embodiment is true or not. As predicted by hypothesis **3)** outlined in the objectives and hypothesis section of the present study, the time to make a laterality judgment of a stimulus reflects the degree of MR needed to bring one's body parts to a position adequate for achieving the task, reflecting on an almost perfect linear increase of RTs with angular stimulus disparity. In other words, this hypothesis predicts that the body can play a constraining role in cognition, independently of whether strong/weak conceptual embodiment is true or not. In sum, assuming that subjects would perform the MR of bodily-related pictures through a 1PP, in which they would simulate the rotation of the human body limbs depicted on the screen as if they were physically rotating their own limbs, it was predicted that subjects would have slower RTs and lower ACC levels for stimuli that were displayed in anatomically awkward positions (e.g. 180º) compared to stimuli displayed in the canonical position (0º), replicating similar results from other studies of MR of bodily-related (e.g. Parsons, 1987a, 1987b). If this prediction was true, then biomechanical constraints of the human body would have played a constraining role in the performance of MR of bodily-related, according to hypothesis **3)**. Data are consistent with hypothesis **3)**. First, as reported by subjects in the self-report in the end of the experiments, subjects reported having rotated the limb displayed on the screen to the canonical position (0º) in order to match with the canonical position of their own limbs. By employing this strategy, subjects spent more time to rotate the picture displayed in anatomically awkward position to the canonical position in order to provide a laterality judgment response. As it can be observed in the results section of the present study, subjects had an almost perfect linear increase in RTs and decrease in ACC levels across the degrees of inclinations in which the body parts were displayed at (0º, 30º, 60º, 90º, 120º, 150º and 180º, respectively). This pattern was observed independently of musical stimuli subject listened to before completing the MR of bodily-related pictures. In sum, since subjects mentally simulated their own body-parts rotation while carrying out the MR of bodily-related pictures and biomechanical constraints implied by the degree of inclination of the body part depicted on the screen interfered in subjects responses, then a constraining role of the non-neural parts of the body in cognition is observed and question **B)** can be answered with an 'yes' in this case.

A good amount of studies have provided conceptual embodiment with suggestive evidence that conceptual embodiment may be true at least for motor concepts. First, as described in the empirical findings of motor imagery section, several studies that employed brain-mapping techniques (e.g. fMRI) have observed that modality-specific areas of the brain, more specifically, the motor areas, are activated during motor imagery tasks (Jeannerod, 2001). The finding that motor imagery relies on the same mechanisms of motor preparation and execution is a not only a central claim in the motor imagery literature, but also accounts for the improvements that sportsmen may have in the physical performance after mentally rehearsing a movement that will be employed during the sporting practice. For instance, as described in that section, in Murphy et al.'s (2008) study, groups of professional golfers who underwent a three-week program of motor imagery and physical practice combined had better performance improvement in bunker shots compared to those groups assigned only to the physical practice of the movements, and did not perform any motor imagery of the task. It is hypothesized by the motor imagery literature that this improvement after subjects employed motor imagery techniques before the sporting practice is due to the reinforcement of the brain areas involved in motor execution when subjects only imagined performing the movements for a period of time (Jeannerod, 2006). Likewise, as reported in diverse sections of the Theoretical Background chapter of the present study, a good amount of studies that employed brain-mapping techniques have reported that it was observed an increased activation in modality-specific areas of the brain, such as the motor areas, in passive reading tasks. For instance, in Hauk et al.'s (2004) study, it was observed that, when presented with words related to leg actions (e.g. KICK), the primary motor area and the premotor cortex involved in leg movements were activated. Taken together, these studies provide with suggestive evidence that weak conceptual embodiment may be true, at least for motor concepts. In line with these studies, it is important to note that the hypothesis that weak conceptual embodiment may be false for motor concepts is just one hypothesis that may account for the null result observed in the experiment in terms of hypotheses **1)** and **2)** described in the objectives and hypotheses section.

Assuming that weak conceptual embodiment is true for motor concepts, these motor concepts are grounded in modality-specific areas of the brain, namely, the motor areas, and we use these motor concepts in order to carry out MR of bodily-related pictures through motor simulation, it is possible to raise some auxiliary hypotheses that may account for the null result in terms of hypotheses **1)** and **2)** that do not particularly suggest that weak conceptual embodiment is false for motor concepts**.**

First, in line with assumption **IV**, that musical rhythmic structures activate the motor areas, varying in degree of activation across different musical rhythmic structures, namely Metric Simple, Metric Complex and Non-metric, according to Grahn and Brett's (2007) study, it was observed that, although Metric Simple, Metric Complex and Non-metric stimuli elicited different levels of cortical activation in the motor areas compared to rest, more specifically in areas such as the pre-SMA, SMA, Ventral Premotor Cortex, Mid-premotor Cortex, Cerebellum, the STG, PMd areas, areas of the Basal Ganglia, such as the Putamen and the Caudate, the levels of activation differed between musicians and non-musicians. In that study, it was observed that these areas were shown to be more activated in musicians than non-musicians after exposure to stimuli. Although Grahn and Brett (2007) noticed that the activation of these brain areas in non-musicians was significantly higher when compared to rest, since all subjects that took part in the present study were non-musicians, it is hypothesized that the cortical activation elicited in brain areas involved in MR of bodily-related pictures after exposure to either Metric Simple Music or Metric Complex Music was not sufficient to result in an increase of subjects' performance at the task, in line with assumption **V**. It could be speculated, then, that musicians would have had better performance at MR tasks after exposure to pieces of music with different rhythmic structures on the basis that neural activation of motor areas after exposure to music is higher for musicians than non-musicians, and we use the same motor areas to simulate bodily movements and to carry out MR tasks of bodily-related pictures. In a meta-analysis on the Mozart Effect, Hetland (2000) claims that very few studies compared the performance of different groups of subjects with different musical expertise (musicians vs. non-musicians, in this case) at spatial-temporal reasoning tasks after exposure to musical stimuli such as Mozart's music. Whereas one study showed no differences in performance between musicians and non-musicians at spatial-temporal reasoning tasks after subjects listened to Mozart, Haydn or remained in silence (Cooper, 1997), another observed that non-musicians outperformed musicians at MR tasks of cubes after listening to Mozart's music (Aheadi et al., 2009). Due to the short amount of studies that investigated the correlation between musical expertise and the Mozart Effect, the hypothesis stated in this paragraph can only be speculative.

Still in line with assumption **IV** and also related to assumption **V,** that claims that increase in activation and synchronization of neural pattern activities in specific brain areas used for spatial-temporal tasks after music listening result in performance enhancement at the task compared to control conditions and other stimuli, it is also hypothesized that, perhaps, listening to the musical stimuli designed for the present study did not elicit activation in *all* areas that are involved in MR of bodily-related pictures. According to Parsons et al. (1995) and Hamada et al. (2018), the areas activated when subjects carry out MR task of bodily-related pictures are: Prefrontal and Insular Premotor areas, the SMA, Anterior Cingulate, right Cingulate, superior Premotor Cortex, bilateral Premotor Cortex, Cerebellum and Basal ganglia, posterior and inferior Parietal Cortex, superior Parietal Regions, inferior Parietal, Visual processing areas (V1 and V2), right Occipital area, bilateral Middle Occipital Gyrus, the right Inferior Parietal lobules and the left Superior and Inferior Parietal lobes. As described in section 4.1.1 of the Theoretical Background, Koelsch (2011) reports that, apart from the primary and secondary auditory cortices, music perception activates the following Broadmann areas (BA): for harmony, meter, rhythm and timbre perception, BA 44 is activated, which comprises the Frontal Cortex and areas such as the Ventral Premotor Cortex, the Dorsolateral Prefrontal Cortex, and the inferior Frontal Gyrus; for melodic and rhythmic grouping, BA 22p is activated, which comprises the STG; BAs 41 and 42 (PAC) and BA 52 (Parainsular area) are responsible for feature extraction of pitch height, pitch chroma, loudness, location; the auditory brainstem and the thalamus seem to be involved in extraction of periodicity, timbre, intensity, and location. Also, recent studies that employed brain-mapping techniques (e.g. Grahn and Brett, 2007; Zatorre et al., 2008) suggest that the motor system is involved in processing musical rhythms, since activities in the SMA, pre-SMA, Ventral Premotor Cortex, Mid-premotor Cortex, Cerebellum, the STG, PMd areas, the Putamen, and the Caudate were detected even for listeners that "passively" listened to the musical stimulus. By taking together the brain areas activated in both MR of bodily-related pictures and during music perception, in particular, the perception of rhythm, it may be the case then that, although music (specially its rhythmic components) activates important cortical areas involved in MR of bodily-related pictures, it did not activate *all* the areas involved in the referred task as suggested by Parsons et al. (1995) and Hamada et al. (2018). In sum, it could be the case that all assumptions (**I-VI**) listed in the objectives and hypotheses section of the present study are correct; however, an auxiliary hypothesis could be that, although MR of bodily-related pictures and rhythmic perception strongly activate the motor cortices of the brain, it is possible that neural activation of the motor cortices elicited by music perception may not be sufficient for performance enhancement at MR of bodily-related pictures, since other essential cortical areas involved in MR of bodily-related pictures may not have been activated by the musical stimuli used in this present study. However, since this study did not employ any brain-mapping technique, it is not possible to conclude that this hypothesis may account for the null effect in terms of the lack of Mozart Effect in the present study.

Alternatively to hypotheses **1)** and **2)** described in the objectives and hypotheses section of the present study, it had been hypothesized that if Rauscher et al. (1993, 1994, 1995) are correct that exposure to complexly structured music results in increase of neural activation and synchronization of neural patterns in modality-specific areas involved in spatial-temporal reasoning tasks, then it would be expected that subjects would have had better performance at MR of bodily-related pictures after listening to Metric Complex Music compared to the other two stimuli, since Metric Complex Music would be a more complex stimulus than the other two, given its complex rhythmic structures, designed according to Bouwer et al.'s (2018) study. This alternative hypothesis would sharply contrast with assumption **IV.** However, as observed by data, there was no significant increase in performance after subjects listened to any of the three stimuli. This lack of performance enhancement could suggest that Rauscher et al. (1993, 1994, 1995) are wrong that complexly structured music elicits synchronization of neural patterns in brain areas involved in MR tasks which, in turn, results in performance enhancement at these tasks compared to other stimuli, such as repetitive and simply structured music (as they mention in their studies, Phillip Glass's music, for instance). Alternatively, it could be the case that, for instance, Metric Complex Music, despite having attributes that would make this stimulus more complex than Metric Simple Music and Silence (in this case, the rhythmic structures), was not 'complex enough' to elicit the synchronization of neural patterns of brain areas suggested by Rauscher et al. (1993, 1994, 1995). This latter hypothesis could further suggest that, perhaps, changing other musical features, such as melody, harmony, pitch, would have been necessary to provide the musical stimulus with the 'complexity' required. In other words, only the rhythmic structures were manipulated in order to give rise to two distinct pieces of music, namely Metric Simple and Metric Complex Music. However, although this manipulation has provided the Metric Complex Music with more ‘complexity’ than the other stimuli, that complexity did not suffice to enhance subjects’ performance at the task, according to Rauscher et al.’s (1993, 1994, 1995) account for the Mozart Effect. Again, it could be the case that the stimuli used in the present study were not suitable for the effect expected at the subsequent task, since they were not complex enough. This hypothesis, however, seems to be hard to be verified. As stated in section 4.2.1, Rauscher et al. (1993, 1994, 1995) have never provided the term ‘complexity’ with a proper definition or have never made any scientific claims about the term ‘complexity’ in music, special in Mozart’s music. This term was brought up in comparison with the structure of other musical stimuli, such as Philip Glass’s repetitive music, however, the authors have never made a scientific claim of what makes Mozart’s music complex *per se*. Due to this lack of scientific claims of what constitutes the complexity of Mozart’s music, it does not seem possible to measure how complex the Metric Complex Music used in this study is, since Rauscher et al. (1993, 1994, 1995) or any other researcher within the Music Perception literature do not offer an absolute precise definition of ‘complexity’ in music, and, as a consequence, whether Metric Complex Music meets Rauscher et al.’s (1993, 1994, 1995) criteria of a musically ‘complex stimulus’.

Besides the hypotheses regarding weak conceptual embodiment, motor imagery, and the musical attributes of the musical stimuli employed in the present study, it is also possible to raise a hypothesis that concerns the experimental setup. Firstly, as described in the methodological section, for this study, students of Sports Science from the Polytechnic Institute of Castelo Branco were recruited to participate in the experiment, who reported performing physical activities on a daily basis. According to Pietsch and Jansen (2011), by comparing performances of students of music, students of sports and students of education in a MR of cubes, the authors found significant differences in students of both music and sports’ performance compared to students of education. As far as the performance of students of sports concerns, Pietsch and Jansen (2011) attribute their good performance at MR tasks to their high motor competence. As reported in the results section, subjects’ performance was relatively high in terms of ACC levels and relatively low RTs across all conditions and even degrees of inclination of the depicted limbs. It can be hypothesized, then, that perhaps the MR of bodily-related pictures was too easy for them, preventing them from showing any improvement in performance and, therefore, significant statistical differences in performance after they listened to any auditory stimuli. Since it was employed a counterbalanced paradigm, in which all subjects listened to all three auditory stimuli in different orders for three consecutive days, if subjects had had a relatively high score on the first day, this score would probably not have improved significantly for the next two days of experiments, regardless of any auditory stimulus they had listened prior to performance. As observed through the data, this was the case for ACC levels, in which subjects scored 85,3% on the first session, 86,4% on the second, and 87,9% on the third, not differing significantly among the three days of experiments. Thus, at least for ACC levels, the relatively good level of subjects at MR of bodily-related tasks may have hindered any improvement subjects could have had along the three sessions of experiments. Secondly, this lack of improvement was not observed for RTs, since it was observed a significantly decrease in RTs across sessions 1, 2 and 3. However, this decrease in RTs across the sessions correlated with the auditory stimulus subjects listened prior to task completion, in which no significant differences in RTs amongst auditory conditions. Therefore, it may be the case that improvement in performance at MR of bodily-related pictures in terms of RTs is sensitive to practice, and not to auditory stimuli subjects listen to before the task.

A final hypothesis for the lack of Mozart Effect in the present study also addresses hypothesis **1)**, but specially addresses hypothesis **2).** Also, the following hypothesis sheds light on assumption **VI**. First, as stated in the section 3.2.1 about the Mozart Effect, different accounts for the Mozart Effect have been produced: On the one hand, according to Rauscher et al. (1993, 1994, 1995, 1998), there is a direct link between exposure to music and spatial reasoning, supported by the trion model (Leng et al, 1990), which proposes that musical activity and other higher cognition functions share inherent neural firing patterns organized in a highly structured spatial-temporal code over large regions of the cortex. Some studies that employed brain-mapping techniques (e.g. Bodner et al., 2001) found differences in activation by the Mozart sonata compared to Beethoven’s Fur Elise in the Dorsolateral Pre-frontal Cortex, Occipital Cortex and Cerebellum, all expected to be important for spatial-temporal reasoning. In other words, according to Rauscher et al.’s (1993, 1994, 1995, 1998), the Mozart Effect is a product of activation of cortical areas involved in spatial-temporal task, giving rise to assumptions **V and VI**. On the other hand, Chabris (1999) claim that the Mozart effect could be explained as an artifact of arousal/mood levels of the subject or to enjoyment caused by listening to Mozart’s music. As described in section 3.2.1, Husain et al. (2002), for instance, edited Mozart’s music and created four different pieces based on the original piece: Mozart with fast tempo and major mode, Mozart with fast tempo and minor mode, Mozart with slow tempo and major mode, Mozart with slow tempo and minor mode. The authors found a correlation between the speed of the new piece (fast or slow) and the arousal levels reported by participants, and a correlation between the mode of the new piece (major or minor) and mood levels reported by participants. In general, participants had better performances at spatial-temporal reasoning tasks after listening to Mozart with fast tempo and major mode compared to the other three pieces. Arousal/mood levels were measured before and after subjects were exposed to the pieces and subjects reported higher levels of arousal and changes of mood after listening to Mozart with fast tempo and major mode. As a conclusion, the authors attribute the increase of performance at spatial-temporal reasoning tasks as a product of changes of arousal levels and mood in subjects, casting doubt on assumption **VI**. In the present study, the levels of arousal and mood were measured before and after exposure to stimuli. As a result, contrary to Husain et al.’s (2002) study, there was no significant increase in arousal levels (in fact, there was a significant decrease in arousal levels after exposure to Metric Complex Music and Silence, but not to Metric Simple Music), and in terms of mood changes, it was only observed that Silence elicited significant alterations on the vigor/activity dimension, in which subjects reported feeling less active after remaining in silence. Since the experiment from the present study did not produce results similar to Husain et al's (2002) in terms of arousal/mood changes, and the Mozart Effect was observed in Husain et al's (2002) study but not in the present study, it can be hypothesized that arousal and mood changes are the reason for the Mozart Effect. The arousal/mood changes account for the Mozart Effect has been replicated elsewhere (Nantais & Schellenberg, 1999; Thompson, Schellenberg & Husain, 2001; Jones, West & Estell, 2006). Apart from suggesting that assumption **VI** may not be true, the hypothesis described in this paragraph would also address to question **C).** For that question, the present hypothesis may suggest that perhaps there were no significant differences in performance after subjects listened to either the musical stimuli or remained in silence because there were no significant increases in arousal/mood levels, as observed in Husain et al.'s (2002) study.

In line with the hypothesis described in the last paragraph, Nantais and Schellenberg (1999) compared subjects' performance at spatial-temporal reasoning tasks after listening to Mozart's music or to a narrated horror story by Stephen King. After completing the task, subjects rated which stimuli they preferred the most. While half of them preferred Mozart's music, the other half preferred the horror story by Stephen King. As a result, authors found a correlation between preference of stimulus and performance, in which there was a Mozart effect for participants who preferred Mozart's music and a Stephen King's effect for those who preferred Stephen King's story. In the present study, participants rated how much they enjoyed the stimuli after exposure. As a result, contrary to Nantais and Schellenberg's (1999) study, there was no significant difference in valence ratings between stimuli, which suggests that subjects had no preference for any particular stimulus. These data suggest that, as subjects did not show preference for a particular stimulus, it could be the case that preference for stimulus is essential for the Mozart Effect, and possibly, one of the reasons why there was no increase of performance after exposure to musical stimuli in the present study. Like the hypothesis stated in the last paragraph, this hypothesis would also suggest that assumption **VI** is false and would also address to question **C)**, suggesting that perhaps the lack of preference for a specific stimulus was the main responsible for the lack of Mozart Effect in the present study.

In sum, from hypotheses **1)**, **2)**, and **3)** outlined in the objectives and hypotheses section of the present work, only hypothesis **3),** which predicted that the non-neural parts of the human body would play a constraining role in the cognitive task, was confirmed. According to data, the biomechanical constraints of the body seem to have played a constraining role in the MR of bodily-related pictures, since subjects took longer and were less accurate to emit a laterality judgment for limbs depicted in biomechanically awkward positions (e.g. 150º and 180º) compared to limbs depicted in canonical position (0º). Thus, if hypothesis **3)** is true, it could be concluded, at least based on the data from the experiment, that body as a constraint on cognition, a form of ECT, is true. As far as failure in observing hypotheses **2)** and **3)** concerns, whereas some of the hypotheses stated in this chapter that address to the failure in observing the Mozart Effect in the present study suggest that one or more assumptions (**I-VI**) may be false, others do not particularly dismiss them. Very importantly, due to lack of use of brain mapping techniques that would have shown which brain areas were activated while subjects either listened to the musical stimuli or underwent the MR of bodily-related pictures, some of the hypotheses raised in this section are just speculations and should be thoroughly investigated in future studies. Apart from the speculative hypotheses, based on this study's data and on the Mozart Effect literature, there seems to be more solid pieces of evidence that suggest that the Mozart Effect may be an artifact or arousal/mood or subjects' preference, since, as discussed, the absence of arousal/mood increase and preference for a particular stimulus may have been the responsible for the lack of Mozart Effect in the present study. However, until all other speculative hypotheses are appropriately addressed, it is too soon to conclude that performance enhancement at spatial-temporal reasoning and like-minded tasks are due to increases in arousal/mood levels or are an artifact of subjects' personal preferences as suggested by some authors in the Mozart Effect literature (Chabris, 1999; Nantais & Schellenberg, 1999; Husain et al. 2002).

2 Study limitations

As mentioned in the discussion section of the present study, one major methodological limitation of the present study was the lack of employment of brain-mapping techniques, such as EEG, fMRI, PET Scan, TMS, etc. Due to the lack of use of these techniques, it was not possible to investigate which brain areas were recruited either while subjects listened to the auditory stimuli or during the MR of bodily-related pictures. As a result, some of the hypotheses that were drawn out to account for the failure in observing both hypotheses **1)** and **2)** outlined in the objectives and hypotheses section of the present study turn out to be speculations based on empirical findings or theoretical assumptions from studies described in the theoretical background section of this dissertation. Ultimately, due to the lack of objective verification of these speculative hypotheses, it is not possible to conclude what was the exact reason behind the failure in replicating the Mozart Effect in the present study.

One of the hypotheses for the failure in replicating the Mozart effect outlined in the last section refers to the subjects recruited to participate in the present study. That is to say, subjects recruited for the experiments formed a homogenous group of students of Sports Science with no musical expertise, as they reported in the demographic questionnaire prior to attending the experiments. The specific hypothesis in question was that Grahn and Brett (2007) observed a significant difference in terms of cortical activation of areas such as the pre-SMA, SMA, Ventral Premotor Cortex, Mid-premotor cortex, Cerebellum, the STG, PMd areas, areas of the Basal Ganglia, such as the Putamen and the Caudate between musicians and non-musicians while they listened to Metric Simple, Metric complex and Non-metric stimuli compared to rest. Thus, it could be the case that non-musicians did not have those areas sufficiently activated in order to enhance their subsequent performance at MR of bodily-related pictures as musicians would possibly have had. Although the aim of the present study was not to particularly investigate differences between musicians and non-musicians at MR of bodily-related pictures, the lack of another group of subjects formed by musicians may not allow us to thoroughly investigate whether the specific hypothesis outlined in this paragraph is true.

For this study, a counterbalanced paradigm was employed for the experiment. As stated in the methodological section of the present study, this paradigm was selected in the light of past studies about the Mozart Effect (Rauscher et al., 1993; Rideout et al., 1998; Gilleta et al., 2003) and studies that investigated the effects of music on imagery (e.g. Tham, 1994). The counterbalanced paradigm allows subjects to receive all experimental conditions, since the experimenter can assign each group to different experimental conditions and these conditions are altered along the experimental sessions. As Pollatsek and Well (1995) point out, within-subjects design allows for more powerful tests than between-subjects design. However, it could have been the case that a 'demand effect' emerged, in which subjects realized the experimenter's intention (in this case, to assess performance at MR of bodily-related pictures after exposure to auditory stimuli) and, as a consequence, may have consciously/unconsciously changed their behavior while carrying out the task after they listened to a stimulus (Rosenthal, 1976; Charness, Gneezy & Kuhn, 2012). This change of subjects' behavior may have limited the reliability of their performance.

The measure of arousal changes both before and after subjects were exposed to any auditory stimulus may pose another limitation to the present study. As described in the methodological section of this study, the use of a self-report questionnaire to measure subjects' arousal levels during the experiment was based on Husain et al's (2002) study. In their study, Husain et al. (2002) claim that physiological measures of arousal may be often unreliable. Since this experiment employed a counterbalanced design, in which subjects were exposed to three different stimuli in different orders for three consecutive days, the possibility of subjects answering the SAM based on a comparison between the stimuli they have already been exposed to (for instance, subjects could have responded the SAM before and after they listened to Metric Complex Music based on the responses they had given on the day before when they had listened to Metric Simple Music) cannot be discarded. Also, as the present study did not measure arousal manifested in the physical dimension of the subject, such as HR, peripheral temperature, galvanic skin response through the employment of specific instruments that measure the body's physiological signals (e.g. heart rate monitor), the subjects' physical reactions in which arousal can be manifested upon (Kuan et al., 2018) were measured by subjects' self-report through the SAM.

The experiment took place in a large room in the Polytechnic Institute of Castelo Branco. The room, however, was not acoustically isolated. Therefore, it cannot be fully discarded the hypothesis that outdoor noises and distractions could have influenced subjects performance at MR of bodily-related pictures (which requires concentration) or influenced the hearing of auditory stimuli, in special, when subjects remained in silence. Most studies about the Mozart Effect or studies that investigate about the imagery phenomenon take place in acoustically isolated rooms in order to keep subjects as concentrated as possible. However, an acoustically isolated room was not available for the experiment on the scheduled dates.

The musical samples used in the experiment carried out in the present study were also limited to a specific musical genre. In this case, musical samples were limited to the genre minimalist/techno, in which the rhythmic structures were edited by the experimenter in order to create two versions of the same musical piece: one version would have Metric Simple rhythmic structures, and another would have Metric Complex rhythmic structures. This method was employed in order to verify whether changing the rhythmic elements of the music would suffice to result in subjects' enhancement in performance in spatial-temporal reasoning tasks, in the light of assumptions **IV** and **V**. However, this selection limits the investigation of other possible variables that may account for other musical features that may be required to enhance subjects' performance at the task, such as genre or other musical elements (e.g. melody, harmony, etc). A suggestion is made in the following section in order to address this limitation.

3 Implications for future studies

To this date, the present study is the first one to investigate the Mozart Effect on MR of bodily-related pictures. As previously discussed, the results shed light on a wide range of topics, such as ECT and conceptual embodiment, motor imagery, music perception and the Mozart Effect. Two hypotheses based on assumptions **I-VI** derived from the Theoretical Background and previous empirical studies were not confirmed, since the Mozart Effect was not observed in the present study. Failure in replicating the Mozart Effect then gave rise to several auxiliary hypotheses in order to provide a reasonable account for the lack of effect observed in the experiment's results.

As pointed out as one of the limitations of the present study, the lack of use of brain-mapping techniques has been crucial for the ultimate lack of confirmation of some of the hypotheses raised to account for the lack of the Mozart Effect. Thus, it would be methodologically valuable to include the use of one of these techniques (e.g. fMRI, PET Scan, EEG, etc.) in follow-up studies. The use of these tools would provide these follow-up studies with suggestive evidence regarding which brain areas were activated while subjects either during pre-treatment tasks (e.g. while subjects listen to auditory stimulus before carrying out the subsequent task) or during the task itself (e.g. MR of bodily-related pictures, in the case of the present study). However, it is important to note some of the consequences that the employment of these techniques would bring for follow-up studies. Firstly, the use of these techniques would probably alter the experimental design of the experiments. In particular, the use of these techniques would probably result in a decrease of number of subjects to be recruited for the experiment. Although the use of these brain-mapping techniques has the advantages already pointed out in this paragraph, it is important to note that, apart from being expensive resources for an experimental study at times, they are also time-consuming resources. In that regard, for instance, an fMRI scanner may only accommodate one subject at the time, and since it is claimed in the Mozart Effect literature (e.g. Rauscher et al., 1993) that the effect takes place when subjects listen to the stimulus for 8-10 minutes, each subject would then have to spend 8-10 minutes inside the scanner. Also, fMRI scanners are noisy at times, so it would be convenient for experimenters to provide subjects with acoustically isolated headphones. Typically, studies that employ these brain-mapping techniques tend to recruit fewer subjects than studies that only measure subjects' behavioral reactions in order to compensate for time constraints (e.g. Hamada et al., 2018), so the experimental design of this present study would probably be altered as a consequence of the employment of brain-mapping techniques. Secondly, still in line with the time constraints that the employment of these techniques might impose, a counterbalanced design would probably consume more time. Taking the fMRI scanner as an example, if subjects had to listen to three different auditory stimuli, each subject would have to spend a total of 24-30 minutes inside the scanner throughout three different days of experiment, increasing the time consumption in the pre-treatment phase. Thus, in this case, it would be convenient, perhaps, to change from a counterbalanced paradigm to a between-subjects paradigm, in subjects are randomly assigned to an experimental group and listen to the auditory stimulus that corresponds that that group. The between-subjects design, however, usually require a larger sample sizes to provide data with strong statistical power (Charness et al., 2012) compared to within-subjects designs, such as the counterbalanced design. Thus, if more subjects are required for the experiment, more time in the pre-treatment phase is required. Finally, when experimenter(s) opt to employ brain-mapping techniques while subjects perform MR of bodily-related pictures or like-minded cognitive tasks, it should be considered that activation of motor areas would be likely to increase when subjects perform a motor action in order to provide with a response (e.g. pressing a keyboard key, pressing a pedal with the foot, etc.). This increase of activation due to motor action should be taken into consideration by the experimenter while carrying out data analysis in order to conclude which exact cortical areas were activated during the motor imagery process, and not during the motor action performance. As observed in the motor imagery section of the present study, not all areas involved in motor performance are involved in motor imagery, and activation during motor imagery typically accounts for 30% of brain activation in the motor areas compared to the physical execution counterpart (Roth et al., 1996; Jeannerod, 2001).

As far as the limitations of the musical samples used in the experiment carried out in the present study concern, in order to fully explore whether changing the rhythmic elements of a musical piece would suffice for the Mozart Effect, in the light of assumptions **IV** and **V**, the edition made to the musical pieces used in this study, in which the rhythmic structures of an original musical piece by Motorcity Soul were manipulated in order to create two different versions of the same piece, namely Metric Simple and Metric Complex versions, could have been applied to a larger extent of musical genres, such as Jazz Music, Rock'n'Roll, Samba, MPB, Classical Music, etc. This would probably demand a larger study with a larger sample size, but it would be interesting to explore whether manipulation of rhythmic structures could have led to a Mozart Effect whether applied to other musical genres rather than minimalist/techno. Likewise, other musical features could have been explored even limited to the specific musical piece adopted for the present study: in this case, the original piece could have had been manipulated in order to transform the complexity of the melody/harmony/pitch, etc. Again, this would require a larger study with a larger sample size. In sum, this study was limited to the investigation of whether listening to different rhythmic structures of the same musical piece would result in a Mozart Effect for one of the conditions (in this case, as hypothesized, the Metric Simple Music); this limitation in terms of musical features manipulated could be held responsible for the lack of Mozart Effect, as suggested in the discussion section. However, on a positive note, the manipulation of rhythmic structures applied in the present study may open new venues for investigation about the musical stimuli that may be used in experiments similar to the one conducted in this study.

In line with the method employed in the present study to select the auditory stimuli, as observed in the discussion section, since there were no significant differences in valence ratings across musical stimuli and there was also no Mozart Effect, it could be the case that the Mozart Effect is an artifact of subjects' auditory preferences, as suggested elsewhere (Nantais & Schellenberg, 1999). It would be interesting to further investigate whether applying the same editing method used in the present study to a musical piece that elicit subjects' preferences (e.g. altering the rhythmic or another musical element of an original version) would influence subjects' performance at the MR of bodily-related pictures compared to the original musical piece, another piece that may not elicit subjects' preferences (edited or not, or even both) and control conditions. By doing this, it would be possible to investigate whether changing a specific musical feature of a musical piece that elicits subjects' preference would increase performance at a subsequent cognitive test. Alternatively, it would be interesting to investigate whether two different musical pieces that elicits similar levels of subjects' preferences would differ in terms of enhancing subjects' performance at a subsequent test. In line with the preference hypothesis, it is also hypothesized that changes in arousal/mood levels are responsible for the Mozart Effect (Husain et al., 2002). This hypothesis could be studied in depth, since it could be investigated whether two different musical stimuli that elicit similar changes in arousal/mood levels lead to differences in performances at the task, or which musical genre elicits the arousal/mood levels that would set subjects onto an optimal state before task completion. These suggestions, however, may slightly depart from the investigation on the effects of music listening on motor imagery-based tasks, such as MR of bodily-related pictures. Thus, these studies would also have to take into account and investigate the role of musical preferences or changes in arousal/mood levels provoked by the music over motor imagery.

As mentioned in the section regarding the limitations of the present study, it was recruited a homogeneous group of students of Sports Science to take part in the experiment. As subjects mentioned in a demographic questionnaire prior to the experimental sessions, none had previous musical experience, therefore, the group was formed by non-musicians. Also, as stated in the discussion section, one hypothesis that may account for the lack of Mozart Effect relates to the ability of sportsmen/sports students in tasks such as MR (Pietsch & Jansen, 2011), leaving no much space for improvement across exposure to different auditory stimuli. In sum, it would be interesting to see follow-up studies comparing differences in performance at MR of bodily-related parts after exposure to auditory stimuli between two or more homogeneous group. One suggestion would be to select similar groups of subjects as Pietsch and Jansen (2011) selected for their experiment. In that study, Pietsch and Jansen (2011) selected groups of students of education, sports and music. As a result, they observed that students of sports and music outperformed the education students. However, their experiment did not involve any auditory stimulus, only a MR task of cubes. It would be interesting, thus, to investigate how these three or more different homogeneous groups would perform at the MR of bodily-related pictures. In line with this suggestion, it would be also interesting to investigate whether other variables may influence on performance at MR of bodily-related pictures after subjects listened to auditory stimuli, such as handedness, gender, age, ethnic background, etc. Some studies regarding these variables have been performed for MR (e.g. Pietsch & Jansen, 2018), gender (Gilleta et al., 2003), ethnic background (Jansen, Paes, Hoja & Machado, 2019) and age (Berg, Hertzog & Hunt, 1982). However these studies only investigated the effect of these variables over MR tasks or the Mozart Effect alone, and not combined, as proposed by the present study.

Finally, regarding the specific task employed in the present study, namely the MR of bodily-related pictures, it would also be interesting to see follow-up studies approaching other means to assess the effects of music on motor imagery or, perhaps, the Mozart effect over distinct categories of imagery. Thus, a similar study to Kosslyn et al’s. (1998) could be carried out, in which subjects were asked to carry out a MR of cubes either by imagining if they were physically rotating the cubes or by imagining an exogenous force, say, an electric motor, performing the task. Applied to the present investigation, it would be interesting to investigate whether the Mozart Effect emerges for one group that employed a specific strategy to accomplish the task. Another venue of research would be to employ other tasks rather than MR of bodily-related pictures or even MR of cubes and other inanimate objects. For instance, studies like Kuan et al.’s (2018), Karageorghis and Lee (2001), and Debarnot and Guillot

(2013), in which it was investigated how the music would affect motor imagery performance and, consequently, physical performance. Although these studies slightly depart from the Mozart Effect in terms of methods and investigation venues, they seem to be reliable means to assess the effects of music on motor imagery.

In sum, due to the novelty of the present study, as some of the hypotheses were not confirmed by the data, a vast amount of questions regarding the theoretical assumptions and methodological framework that laid foundations for the present experiment can be raised. These questions are essential in order to guide future research on ECT, conceptual embodiment, motor imagery, MR, music perception, and the Mozart Effect, and aid in the setting up of experimental procedures that may thoroughly investigate these topics combined, as the present study attempted to do.

V. Conclusion

The present study aimed to investigate the effect of listening to musical pieces with different rhythmic structures on a cognitive task that relies upon motor imagery mechanisms, namely, MR of bodily-related pictures. This investigation was motivated by a wide range of topics within the ECT and Music Psychology literature. Firstly, findings from empirical studies within the ECT suggest that body can play a constitutive and a constraining role on cognition, and that motor concepts are grounded in modality-specific systems of the brain, namely, the motor cortices (Barsalou, 1999; Wilson and Foglia, 2017). These motor concepts are claimed to be used while we perform motor imagery, the simulation of our own bodily movements (Jeannerod, 2001). Likewise, MR of bodily-related tasks seems to rely on motor imagery mechanisms to be performed (Parsons et al., 1995). Secondly, perception of the rhythmic elements of the music seems to activate the motor cortices, in which the degree of activation varies according to the rhythmic complexity of the stimulus (Grahn & Brett, 2007). Finally, one account for the Mozart Effect suggests that subjects have increased performance at spatial-temporal reasoning tasks due to the priming of cortical areas involved in the task elicited by Mozart's or similar music (Rauscher et al., 1993).

Based on these findings, a MR of bodily-related pictures was carried out, in which subjects performed the task after listening to musical pieces that varied in rhythmic complexity. One out of three hypotheses raised was confirmed, suggesting that the biomechanical constraints of subjects' bodies have played a constraining role on task. The other two hypotheses, however, were not observed, failing in the replication of the Mozart Effect. This lack of Mozart Effect gave rise to several auxiliary and speculative hypotheses, in which the hypothesis with stronger pieces of evidence was that the Mozart Effect is due to differences in arousal/mood changes or is an artifact of subjects' preferences.

Future research should thoroughly address the hypotheses raised in order to account for the failure to replicate the Mozart Effect in the present study. It is strongly suggested that brain-mapping techniques such as PET Scan, fMRI, EEG are employed in follow-up studies in order to further investigate which brain mechanisms are activated in the tasks proposed in the present study, namely, auditory listening and MR of bodily-related pictures. Apart from combining methods from Cognitive Psychology and Cognitive Neuroscience, the addition of brain-mapping techniques would provide a greater understanding about ECT, conceptual embodiment, motor imagery, music perception and the Mozart Effect, and therefore, would provide clearer pieces of evidence of why the Mozart Effect did not emerge in the present study.

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APPENDIXES

Appendix I – Demographic Questionnaire + informed consent (in European Portuguese)

ESTUDO SOBRE TAREFAS DE ROTAÇÃO MENTAL DE IMAGENS CORPORAIS

Prezado(a),

Sou estudante de Mestrado em Ciência Cognitiva pela Universidade de Lisboa. Gostaria de o(a) convidar para participar de um estudo que estou a desenvolver para a minha dissertação de Mestrado, que terá como foco a investigação de processos de formação de imagens mentais a partir da execução de tarefas de rotação mental de imagens de membros do corpo humano.

As informações colhidas neste questionário bem como as respostas dadas ao longo das tarefas de rotação mental serão mantidas sob sigilo, somente utilizadas para fins de recolha de dados para o posterior desenvolvimento da Dissertação.

A experiência consistirá em escutar trechos de peças musicais e realizar, posteriormente, tarefas de rotação mental de imagens do corpo.

As respostas pertinentes às tarefas de rotação mental devem ser adequadas às instruções estabelecidas antes do início da sessão prática e da sessão crítica da experiência, pelo que se aconselha a leitura atenta de cada uma das introduções.

Previsivelmente, a experiência demorará entre 30 a 40 minutos a ser executada, podendo ser pausada a qualquer momento caso o experimentador e/ou o(s)/a(s) participantes julguem necessário. **IMPORTANTE:** A experiência exigirá a participação do participante pelo período total de 3 (dias) consecutivos.

Caso haja alguma dúvida, contacte o experimentador.

Bom trabalho!

DECLARAÇÃO DE CONSENTIMENTO INFORMADO

“Motor Imagery and Music: the influence of music on Mental Rotation tasks in the light of Embodied Cognition Theory”

Declaro ter tomado conhecimento e aceitar participar, voluntariamente, num estudo que tem por objectivo a investigação de processos imagéticos a partir da execução de tarefas de rotação mental de imagens corporais . Para esse efeito, aceito que sejam feitas as tarefas de rotação mental após a escuta de estímulos musicais conforme acima mencionado.

Autorizo que os dados obtidos sejam armazenados de acordo com legislação em vigor, podendo apenas ser utilizados para o estudo acima. Poderei, no entanto, revogar a autorização para utilização dos meus dados em qualquer momento.

Declaro ainda que os resultados dos estudos realizados com os meus dados poderão ser usados em comunicações e publicações científicas de forma anónima.

O estudo proposto foi-me claramente explicado e tive oportunidade de colocar questões. Recebi uma cópia desta declaração devidamente assinada e datada.

Data, Nome e assinatura do participante/seu representante legal

____

Discuti este estudo com o participante, utilizando uma linguagem compreensível e apropriada. Informei adequadamente o participante sobre a natureza deste estudo e sobre os seus possíveis benefícios e riscos. Considero que o participante compreendeu a minha explicação.

Data, Nome e assinatura do Professor/Investigador responsável

____

DADOS DO(A) PARTICIPANTE

Nome: ____

Idade: ☐ 0 a 14 anos ☐ 15 – 24 anos ☐ 25 - 54 anos ☐ 55 – 65 anos ☐ +65 anos

Gênero: ☐ Masculino ☐ Feminino

Estado Civil: ☐ Solteiro(a) ☐ Casado(a) ☐ Divorciado(a)/Separado(a) ☐ Viúvo(a)

Nacionalidade: _______________________________

Possui algum problema de saúde?

☐ Não

☐ Sim. Qual(is)? ____

Possui algum déficit auditivo?

☐ Não

☐ Sim

Possui algum déficit visual?

Não

☐ Sim

HISTÓRICO E PREFERÊNCIAS MUSICAIS

Você gosta de escutar música?

☐ Sim ☐ Não

Qual(is) é (são) o(s) seu(s) gênero(s) musical(is) favorito(s)?

☐ Música Clássica ☐ Pop Music ☐ Country Music ☐ Jazz Music ☐ Blues

☐ Rap/Hip-Hop ☐ Rock/Classic Rock ☐ Techno/Dance ☐ Outros

Com qual periodicidade você costuma escutar música?

☐ Todos os dias

☐ 3 vezes por semana

☐ 2 vezes por semana

☐ 1 vez por semana

☐ Algumas vezes ao mês

☐ Outros

Por quantas horas diárias você costuma escutar música?

☐ Não escuto diariamente

☐ 1 hora

☐ 2 horas

☐ 3 horas

☐ 4 horas ou mais

Você costuma escutar música enquanto desempenha as seguintes tarefas?

☐ Estudar ☐ Trabalhar ☐ Praticar desporto ☐ Meditar ☐ Conduzir automóveis

☐ Dançar ☐ Praticar atividades religiosas ☐ Outros

Você toca algum instrumento musical?

☐ Sim. Qual? ____________________________

☐ Não

Você já estudou música?

☐ Sim, por um ano

☐ Sim, por dois anos

☐ Sim, por três anos

☐ Sim, por cinco anos ou mais

☐ Nunca

Appendix II – European Portuguese version for the MIQ3

Movement Imagery Questionnaire-3, versão portuguesa

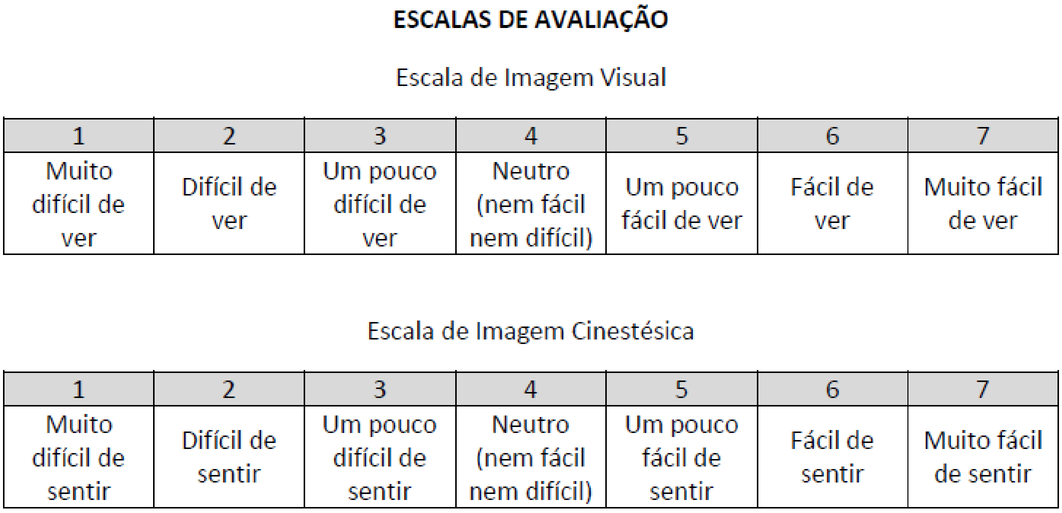
Questionário Completo com Instruções

Instruções

Este questionário diz respeito a duas formas de desempenho mental de movimentos, as quais são usados por algumas pessoas mais que outras, e são mais indicadas para alguns tipos de movimentos do que outros. Primeiro tenta-se formar uma imagem visual ou a figura do movimento na mente. Segundo tenta-se sentir a execução da ação sem realmente realizar o movimento. Será solicitado para realizares ambas as tarefas mentais em movimentos variados neste questionário, e de seguida classificar qual a facilidade/dificuldade encontrada na realização das tarefas. As classificações que atribuíres não estão designadas para avaliar a facilidade ou dificuldade da forma como realizas-te as tarefas mentais. Elas são tentativas para descobrir a capacidade individual para a realização das tarefas para movimentos diferentes. Não existem classificações certas ou erradas ou classificações melhores que outras.

Cada uma das seguintes declarações descreve uma ação particular ou movimento. Lê cada declaração cuidadosamente e de seguida realiza o movimento como é descrito. Realiza o movimento uma única vez. Retorna para a posição inicial como se fosses realizar a ação, uma segunda vez. Depois, dependendo do que te for pedido para realizar, ou (1) formar de forma clara e vivída, quanto possível, a imagem visual do movimento realizada apenas a partir de uma perspetiva interna (i.e. a partir da perspetiva da 1ª pessoa, como se estivesses realmente dentro de ti realizando e vendo a ação através dos teus olhos), (2) formar de forma clara e vivida, quanto possível, a imagem visual do movimento realizada apenas a partir de uma perspetiva externa (i.e. a partir da perspetiva da 3ª pessoa, como se te estivesses a ver num DVD), ou (3) tentar sentir-te a realizar o movimento acabado de executar sem realmente realizá-lo.

Após teres completado a tarefa mental requerida, classifica a facilidade/dificuldade com que foste capaz de realizar a tarefa. Tira a tua classificação a partir da escala fornecida. Tenta ser o mais preciso possível e leva o tempo que sentires necessário para chegares à classificação adequada para cada movimento. Podes escolher a mesma classificação para qualquer número de movimentos "vistos" ou "sentidos" e não é necessário utilizar toda a amplitude da escala.



ESCALAS DE AVALIAÇÃO

Escala de Imagem Visual

1	2	3	4	5	6	7
Muito difícil de ver	Difícil de ver	Um pouco difícil de ver	Neutro (nem fácil nem difícil)	Um pouco fácil de ver	Fácil de ver	Muito fácil de ver

Escala de Imagem Cinestésica

1	2	3	4	5	6	7
Muito difícil de sentir	Difícil de sentir	Um pouco difícil de sentir	Neutro (nem fácil nem difícil)	Um pouco fácil de sentir	Fácil de sentir	Muito fácil de sentir

1. **POSIÇÃO INICIAL:** Coloca-te com os pés e pernas juntas e os braços ao longo do corpo.

   AÇÃO: Levanta o joelho direito o mais alto possível de forma a permaneceres de pé sob a tua perna esquerda, com a perna direita fletida (dobrada) no joelho. Agora baixa a tua perna direita para voltares a estar de pé sob os dois pés. A ação é executada lentamente.

   TAREFA MENTAL: Assume a posição de inicial. Tenta sentir-te a realizar o movimento já observado sem o executar. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa mental.

   Classificação_____

2. **POSIÇÃO INICIAL:** Coloca-te com os pés e pernas juntas e os braços ao longo do corpo.

   AÇÃO: Curva-te para baixo e de seguida salta em linha reta para cima, o mais alto possível, com ambos os braços estendidos acima da cabeça. Aterra com os pés afastados e baixa os braços.

   TAREFA MENTAL: Assume a posição de inicial. Tenta ver-te a realizar o movimento já observado a partir da perspetiva interna. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa mental.

   Classificação_____

3. **POSIÇÃO INICIAL:** Estende o braço da tua mão não-dominante para o lado do corpo de maneira que ele fique paralelo ao solo com a palma da mão para baixo.

   AÇÃO: Desloca o teu braço para frente do corpo (ainda paralelo ao solo). Mantem o braço estendido durante o movimento, executando-o lentamente.

   TAREFA MENTAL: Assume a posição inicial. Tenta ver-te a realizar o movimento já observado a partir da perspetiva externa. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa mental.

   Classificação_____

4. **POSIÇÃO INICIAL:** Coloca-te com os pés ligeiramente afastados e os braços completamente estendidos acima da cabeça.

AÇÃO: Lentamente dobra o teu corpo para frente pela cintura tentando tocar nos dedos dos pés com a ponta dos dedos das mãos (ou, se possível, tocar no solo com a ponta dos dedos ou com as mãos). Agora volta à posição inicial permanecendo direito com os braços estendidos sobre a cabeça.

TAREFA MENTAL: Assume a posição de inicial. Tenta sentir-te a realizar o movimento já observado sem o executar. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa mental.

Classificação_____

5. **POSIÇÃO INICIAL:** Coloca-te com os pés e pernas juntas e os braços ao longo do corpo.

AÇÃO: Levanta o joelho direito o mais alto possível de forma a permaneceres de pé sob a tua perna esquerda com a perna direita fletida (dobrada) no joelho. Agora baixa a tua perna a tua perna direita para voltares a estar de pé sob os dois pés. A ação é executada lentamente.

TAREFA MENTAL: Assume a posição de inicial. Tenta ver-te a realizar o movimento já observado a partir da perspetiva interna. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa mental.

Classificação_____

6. **POSIÇÃO INICIAL:** Coloca-te com os pés e pernas juntas e os braços ao longo do corpo.

AÇÃO: Curva-te para baixo e de seguida salta em linha recta para cima, o mais alto possível, com ambos os braços estendidos acima da cabeça. Aterra com os pés afastados e baixa os braços.

TAREFA MENTAL: Assume a posição inicial. Tenta ver-te a realizar o movimento já observado a partir da perspetiva externa. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa mental.

Classificação_____

7. **POSIÇÃO INICIAL:** Estende o braço da tua mão não-dominante para o lado do corpo de maneira que ele fique paralelo ao solo com a palma da mão para baixo.

AÇÃO: Desloca o teu braço para frente do corpo (ainda paralelo ao solo). Mantem o braço estendido durante o movimento, executando-o lentamente.

TAREFA MENTAL: Assume a posição de inicial. Tenta sentir-te a realizar o movimento já observado sem o executar. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa mental.

Classificação_____

8. **POSIÇÃO INICIAL:** Coloca-te com os pés ligeiramente afastados e os braços completamente estendidos acima da cabeça.

AÇÃO: Lentamente dobra o teu corpo para frente pela cintura tentando tocar nos dedos dos pés com a ponta dos dedos das mãos (ou, se possível, tocar no solo com a ponta dos dedos ou com as mãos). Agora volta à posição inicial permanecendo direito com os braços estendidos sobre a cabeça.

TAREFA MENTAL: Assume a posição de inicial. Tenta ver-te a realizar o movimento já observado a partir da perspetiva interna. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa mental.

Classificação_____

9. **POSIÇÃO INICIAL:** Coloca-te com os pés e pernas juntas e os braços ao longo do corpo.

AÇÃO: Levanta o joelho direito o mais alto possível de forma a permaneceres de pé sob a tua perna esquerda com a perna direita fletida (dobrada) no joelho. Agora baixa a tua perna a tua perna direita para voltares a estar de pé sob os dois pés. A ação é executada lentamente.

TAREFA MENTAL: Assume a posição inicial. Tenta ver-te a realizar o movimento já observado a partir da perspetiva externa. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa.

Classificação_____

10. **POSIÇÃO INICIAL:** Coloca-te com os pés e pernas juntas e os braços ao longo do corpo.

AÇÃO: Curva-te para baixo e de seguida salta em linha reta para cima, o mais alto possível, com ambos os braços estendidos acima da cabeça. Aterra com os pés afastados e baixa os braços.

TAREFA MENTAL: Assume a posição de inicial. Tenta sentir-te a realizar o movimento já observado sem o executar. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa mental.

Classificação_____

11. **POSIÇÃO INICIAL:** Estende o braço da tua mão não-dominante para o lado do corpo de maneira que ele fique paralelo ao solo com a palma da mão para baixo.

AÇÃO: Desloca o teu braço para frente do corpo (ainda paralelo ao solo). Mantem o braço estendido durante o movimento, executando-o lentamente.

TAREFA MENTAL: Assume a posição de inicial. Tenta ver-te a realizar o movimento já observado a partir da perspetiva interna. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa mental.

Classificação_____

12. **POSIÇÃO INICIAL:** Coloca-te com os pés ligeiramente afastados e os braços completamente estendidos acima da cabeça.

AÇÃO: Lentamente dobra o teu corpo para frente pela cintura tentando tocar nos dedos dos pés com a ponta dos dedos das mãos (ou, se possível, tocar no solo com a ponta dos dedos ou com as mãos). Agora volta à posição inicial permanecendo direito com os braços estendidos sobre a cabeça.

TAREFA MENTAL: Assume a posição inicial. Tenta ver-te a realizar o movimento já observado a partir da perspetiva externa. Agora classifica a facilidade/dificuldade encontrada na realização da tarefa.

Classificação_____

Movement Imagery Questionnaire-3, versão portuguesa

Formulário de Resposta

(se as instruções e os itens forem lidos aos participantes)

Após teres completado a tarefa mental requerida, classifica a facilidade/dificuldade com que foste capaz de realizar a tarefa no espaço em baixo. Tira a tua classificação a partir da escala fornecida. Tentas ser o mais preciso possível e leva o tempo que sentires necessário para chegares à classificação adequada para cada movimento. Podes escolher a mesma classificação para qualquer número de movimentos "vistos" ou "sentidos" e não é necessário utilizar toda a amplitude da escala.

ESCALAS DE AVALIAÇÃO

Escala de Imagem Visual

1	2	3	4	5	6	7
Muito difícil de ver	Difícil de ver	Um pouco difícil de ver	Neutro (nem fácil nem difícil)	Um pouco fácil de ver	Fácil de ver	Muito fácil de ver

Escala de Imagem Cinestésica

1	2	3	4	5	6	7
Muito difícil de sentir	Difícil de sentir	Um pouco difícil de sentir	Neutro (nem fácil nem difícil)	Um pouco fácil de sentir	Fácil de sentir	Muito fácil de sentir

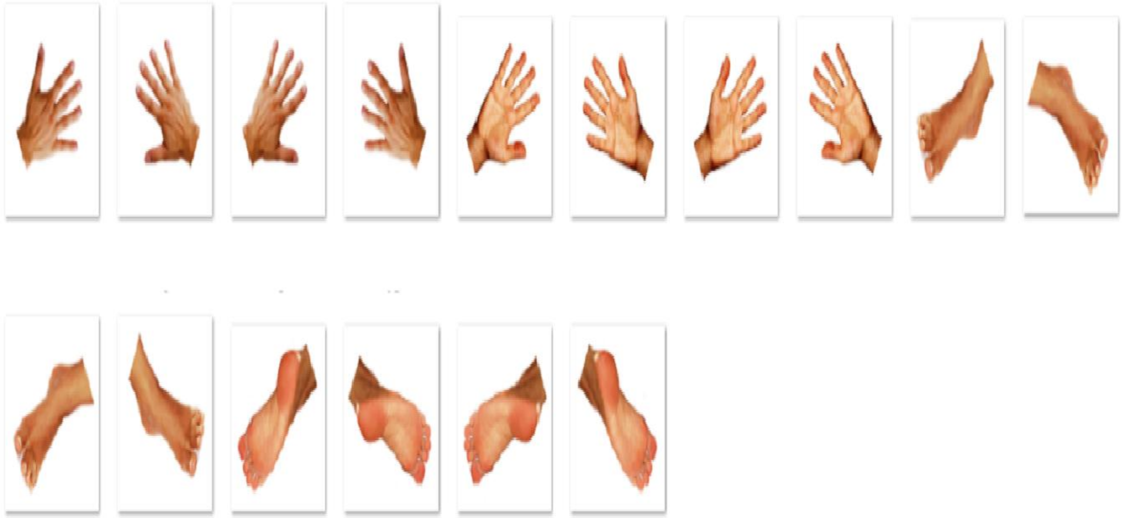
1) Levantar o joelho	Classificação:____	7)Movimento do braço	Classificação:____
2) Salto	Classificação:____	8) Dobrar a cintura	Classificação:____
3)Movimento do braço	Classificação:____	9) Levantar o joelho	Classificação:____
4) Dobrar a cintura	Classificação:____	10)Salto	Classificação:____
5) Levantar o joelho	Classificação:____	11) Movimento do braço	Classificação:____
6) Salto	Classificação:____	12) Dobrar a cintura	Classificação:____

Appendix III – Bodily-related pictures used in the critical trials

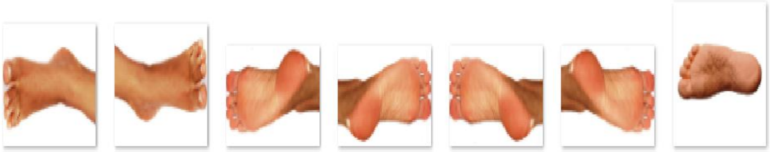
0º:

30º:

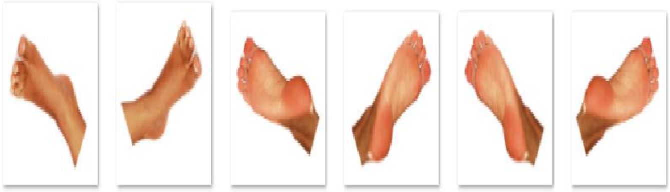
60º:



90º:



120º



150º

180º





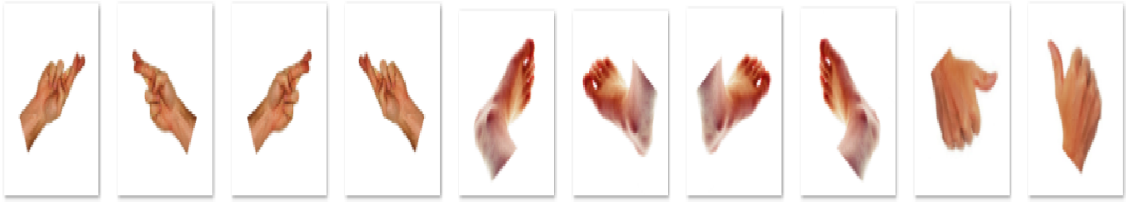


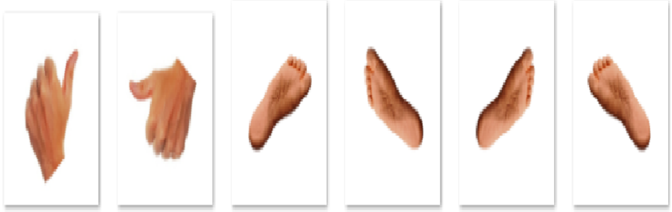

Appendix IV – Bodily-related pictures used in the practice trials

0º

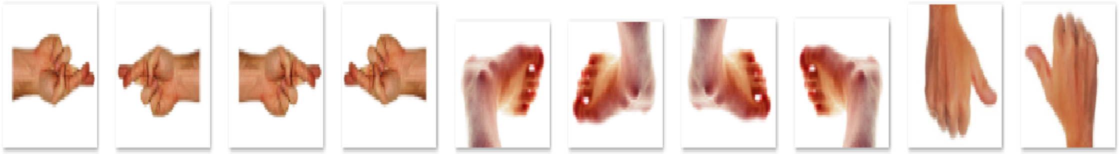
30º

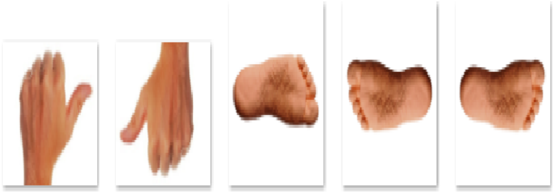
60º



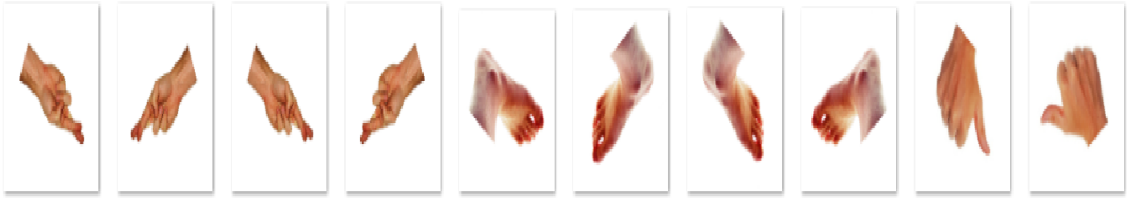


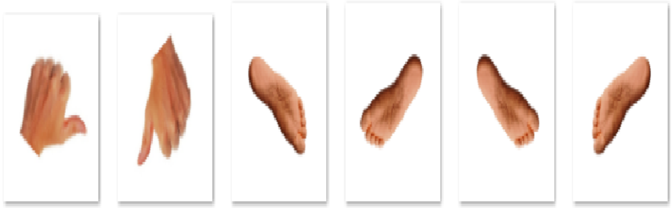
90º



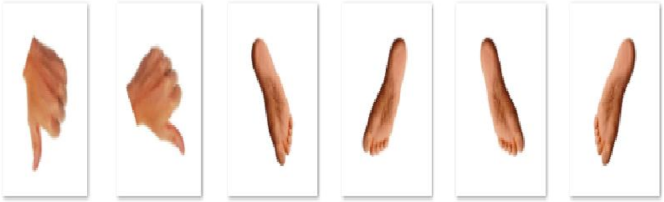


120º





150º



180º

Appendix V – SAM for arousal levels (in European Portuguese)

“Motor Imagery and Music: the influence of music on Mental Rotation tasks in the light of Embodied Cognition Theory”

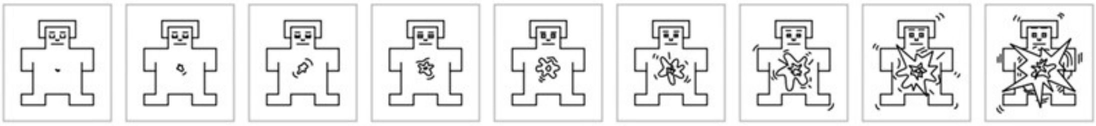
A escala disponível abaixo tem como objetivo mensurar o nível de activação psicofisiológica que você está a sentir neste determinado momento.

Em relação à ativação psicofisiológica, aponte o seu nível de activação mediante a escala de 1 a 9 disponível abaixo, onde a nota 1 equivale a “Extremamente calmo”, e a nota 9= “Extremamente activado”. Por exemplo, utilize as notas de 1 a 9 como referência quantitativa para emitir uma resposta referente ao teu respetivo estado de activação psicofisiológica.

É de se salientar que não existe resposta certa ou errada, apenas a tua resposta!

Bom Trabalho!

ACTIVAÇÃO



Completamente calmo/a

Nem calmo/a Nem activado/a

Completamente Activado/a

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

Appendix VI – POMS (in European Portuguese)

POMS Adaptação por Viana, Almeida e Santos, 2001

NOME

DATA:

Instruções: São apresentadas abaixo uma série de palavras que descrevem sensações que as pessoas sentem no dia-a-dia. Leia primeiro cada palavra com cuidado. Depois, assinale com uma cruz (X) a quadrícula que melhor corresponda à forma como se tem sentido ao longo dos ÚLTIMOS SETE DIAS INCLUINDO O DIA DE HOJE.

		Nada	Um pouco	Moderadamente	Bastante	Muitissimo
		0	1	2	3	4
1	Tenso					
2	Irritado					
3	Imprestável					
4	Esgotado					
5	Animado					
6	Confuso					
7	Triste					
8	Activo					
9	Mal-humorado					
10	Enérgico					
11	Sem valor					
12	Inquieto					
13	Fatigado					
14	Aborrecido					
15	Desencorajado					
16	Nervoso					
17	Só					
18	Baralhado					
19	Exausto					
20	Ansioso					
21	Deprimido					
22	Sem energia					
23	Miserável					
24	Desnorteado					
25	Furioso					
26	Eficaz					
27	Cheio de vida					
28	Com mau feitio					
29	Tranquilo					
30	Desanimado					
31	Impaciente					
32	Cheio de boa disposição					
33	Inútil					
34	Estourado					
35	Competente					
36	Culpado					
37	Enervado					
38	Infeliz					
39	Alegre					
40	Inseguro					
41	Cansado					
42	Apático					

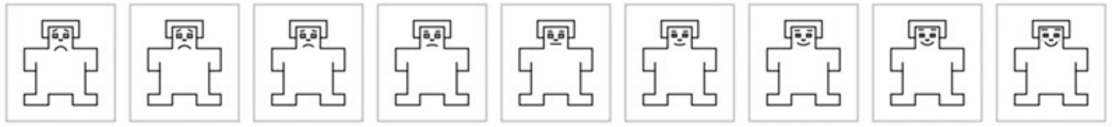
Appendix VII – SAM for Valence (in European Portuguese)

Valência

Nesta página, você irá apontar o grau de valência correspondente ao estímulo ao qual você agora foi submetido.

O grau de valência corresponde ao quão agradável você considera o estímulo, sendo que você irá, novamente, indicar uma nota dentro de uma escala de 0 a 9. Por exemplo, para um estímulo que consideres ser nem agradável nem desagradável, pode-se atribuir ao mesmo um valor médio na escala (por exemplo, 5), no intuito de refletir a avaliação do estímulo como "neutro".

VALÊNCIA



Completamente desagradável				**Nem desagradável Nem agradável**				**Completamente agradável**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

Appendix VIII – 9-point Likert-Scale for beat perception (in European Portuguese)

Estímulos musicais

Para a questão abaixo, considere o termo ''batida'' como notas rítmicas que marcam o andamento métrico dentro do tempo de uma música, sendo, por muitas vezes, um pulso estável e regular que ocorre ao longo da música. O termo ''ritmo", por outro lado, é o fluxo da música ao longo do tempo, usualmente construído sobre as batidas do respectivo estímulo musical. Aponte um valor na escala abaixo, onde 1 equivale a “Não consegui sentir/acompanhar as batidas da música em nenhum momento” e 9 equivale a “Consegui sentir/acompanhar as batidas da música em todos os momentos”.

Questão: Em uma escala de 1 a 9, qual foi o grau de dificuldade para sentir/acompanhar as batidas desta música?

Não consegui sentir/acompanhar as batidas em nenhum momento durante a música

Consegui sentir/acompanhar as batidas durante todos os momentos da música

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

Glossary for musical terminologies

Accent: Acoustic event that is more salient than its surrounding context, caused by differences in physical properties of the sound, such as pitch, intensity or timbre, or by the variation in the grouping structure of a rhythm, e.g. its beats (Bouwer et al., 2018).

Bar (measure): In music notation, bars are vertical lines marked on a stave to denote the point of metrical division of a musical piece, in which a specific number of musical sounds (musical notes, beats, etc.) are organized within this measure, according to a time signature (Kennedy, 1980). Figure **6.1** depicts examples of bars.

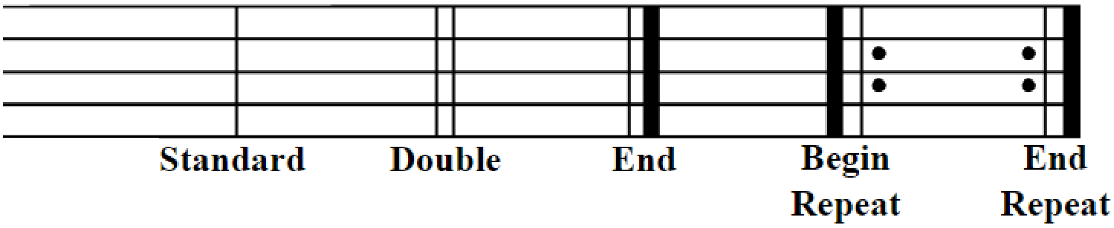


Figure 6.1: Types of bar lines. The Standard is a bar that indicates the end of a measure. The Double bar indicates the end of a section. The End bar indicates the end of a musical piece. The Begin Repeat and End Repeat indicate a measure that should be played twice by the musician (or as many times as indicated). Image retrieved from www.mightyexpert.com on 31st August, 2019.

Beat: The basic unit of measure of rhythmic pulse in music. Groups of beats embedded in a hierarchical organization (metrical system) underlie rhythm. For instance, in a waltz, usually notated as a triple meter (3/4), there are 3 beats to the bar (Kennedy, 1980; Bower et al., 2018).

Harmony: Two or more musical sounds superimposed or occurring simultaneously through frequencies, pitches or chords (Malm, 1996).

Inter Onset Temporal Intervals: "A series of successive notes (of equal durational value) which act as a perceptual ground in which to track the various durational periodicities of metric and rhythmic cycles" (Jordan, 2014, p. viii).

Melody: Succession of simple sounds and silence produced by a single voice or instrument that the listener perceives as a single entity. Series of successive sounds and silence that form a tune, phrase or motive of a musical piece (Stainer & Barrett, 2009).

Meter (metric): "Timing framework under which a pattern of rhythmic durations is understood. Meter organizes the perceived series of beats into regularly repeating patterns of stressed and unstressed beats" (Levitin et al., p. 53). This recurring pattern of beats is generally indicated by time signature that appears at the beginning of the composition. Meter is usually classified by the number of beats per measure and the correspondent unit of subdivision of the beat, such as, for instance, duple meter (each measure divided into two beats, or a multiple number; e.g. 2/2 time signature), triple meter (each measure divided into three beats, or a multiple number; e.g. 3/4 time signature), quadruple meter (each measure divided into four beats, or a multiple number; e.g. 4/4 time signature), quintuple meters, sextuple, etc.(Benward & Saker, 2003). Figure **6.2** depicts an example of a quadruple meter.

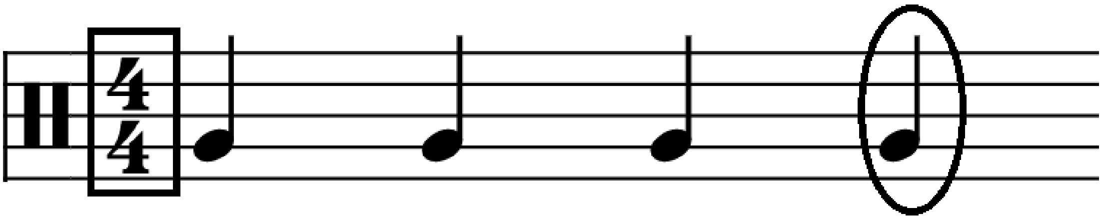


Figure 6.2: Depiction of a quadruple meter. Inside the rectangle there is the time signature of the designated bar with four musical notes, namely a 4/4 time signature. The number four at the top refers to the number of beats (in this case, four beats) to occur within that measure. The number four at the bottom corresponds to the unit of subdivision of the beat being counted; in this case, a quarter note (the musical symbol within the circle at the far right of the bar) is the musical symbol that corresponds to one unit of beat in a quadruple meter. Music sheet rendered through ww.noteflight.com

Offbeat: In a quadruple-meter, usually the first beat of the group of four beats within the bar (measure) is the strongest accented one, as observed in Grahn and Brett's (2007) study. Likewise, subdivisions of the beat within the meter (such as eight notes or sixteenth notes, in the case of a quadruple-meter) may fall in between two beats within the measure, being also characterized as offbeat. Figure **6.3** provides an example of offbeat notes within a 4/4 measure.

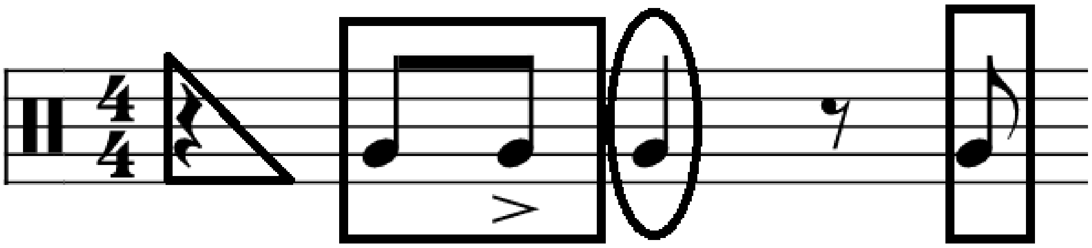


Figure 6.3: A quadruple-meter measure (bar) with a grouping of beats. The symbol inside the triangle is a symbol of a musical pause of a quarter note in the place correspondent to the first beat of the bar. Inside the square there are two eight notes, which have shorter durations than the quarter notes (e.g.

the third note inside the circle is a quarter note) and an accented beat is placed in the second beat inside the square, characterized as an accented offbeat. Finally, the two figures at the right hand side are a pause of an eight note and an eight note (inside the rectangle). The note inside the rectangle can be seen as another example of an offbeat within this particular meter. Musical sheet rendered through www.noteflight.com

Pitch: Location of the sound on a tonal scale according to the rate of vibrations produced by source of the sound, in which fast vibrations yield high-pitched sounds and slow vibrations produced low-pitched sounds. The rate of vibration per second is known as the frequency of the sound waves, quantified as Hertz (Hz; Kennedy, 1980).

Rhythm: Pattern of time intervals demarcating a sequence of stimulus events, perceived as points in time (e.g. units of beats grouped together within a meter). Constituted by distinct temporal sub-units that contribute to the organization and perception of rhythm in music, such as pattern, meter and tempo (Thaut, Trimarchi & Parsons, 2014; Levitin et al., 2018).

Tempo: Rate of speed of a musical piece, usually measured by beats per minute (BPM). Different rates of speed at which the musical piece is being played are most commonly characterized by Italian terms such as, for instance, *prestissimo* (200-208 BPM), *presto* (168-200 BPM), *allegro* (120-168), *moderato* (108-120 BPM), *andante* (76-108 BPM), *adagio* (66-76 BPM), *larghetto* (60-66 BPM) and *largo* (40-60 BPM; Randel, 1986).