Motor Imagery Research: What Does It Offer for New Digital Musical Instruments?

Sair Sinan Kestelli
Center for Advanced Studies in Music
Istanbul Technical University
Macka Campus 34367 Istanbul
kestelli@itu.edu.tr

ABSTRACT

There have been more interest and research towards multisensory aspects of sound as well as vision and movement, especially in the last two decades. An emerging research field related with multi-sensory research is 'motor imagery', which could be defined as the mental representation of a movement without actual production of muscle activity necessary for its execution.

Emphasizing its close relationship and potential future use in new digital musical instruments (DMI) practice and reviewing literature, this paper will introduce fundamental concepts about motor imagery (MI), various methods of measuring MI in different configurations and summarize some important findings about MI in various studies. Following, it will discuss how this research area is related to DMI practice and propose potential uses of MI in this field.

Author Keywords

multisensory processing, mental image, motor imagery, digital musical instruments, embodiment.

ACM Classification

A.1 [General Literature] Introductory and Survey

H.5.2 [Information Interfaces and Presentation] User Interfaces --- Evaluation/Methodology

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing

1. INTRODUCTION

Sound is a physical as well as auditory phenomenon and there is an intimate relationship and interaction process between auditory and other senses such as motor, visual and tactile, starting from physical domain extending through ecological and psychological domains. With the revolutionary shift from behavioral psychology towards cognitive psychology starting from 1960s [36] and availability of technologies to monitor and inspect cognition processes, there have been more interest and research towards multisensory aspects of sound as well as vision and motor action, especially in the last two decades [5] [29]. Right now, with availability of great range of measurement tools, dedicated conferences such as the International Multisensory Research Forum and multi-disciplinary research studies and textbooks, multi-sensory processing research made a great progression to become a well-established research practice [22].

A core element of this emerging research field is 'mental imagery', which is defined at Stanford Encyclopedia of Philosophy as 'a quasi-perceptual experience occurring in the absence of the appropriate perceptual stimuli' [37]. It was also frequently explained with phrases such as 'seeing in the mind' s eye' or 'visualization' because of the dominance of visual senses [22] and used as 'mental simulation' and 'mental representation' in various studies [1] [7] [36]. A comprehensive discussion about the concept could be found in Thomas [36].

An example of formation of different imageries could be given at the event of 'grating an onion'. Thinking about this event in the absence of appropriate stimuli could form auditory (sound of the grating process), visual (visual image of grater, onion and grating hand), motor (bodily experience of holding onion and applying force onto the surface of the grater in a specific way), olfactory (smell of a grated onion) and gustatory (taste of a grated onion) imageries. Additional physiological imageries (formation of teardrops) could also be formed by mental simulation of this event.

This paper will present a short review of motor imagery (MI) research including definition, measurement and siginificant findings from literature. Following, it will discuss how this research area is related to digital musical instruments (DMI) practice and propose potential uses of MI in this field.

2. MI RESEARCH: A SHORT REVIEW

2.1 Definition and Concept

The focus of this paper, 'motor imagery', was defined by Collet et al [1] as ‘the mental representation of a movement without actual production of muscle activity necessary for its execution’.

Jeannerod [17] approached the concept as an element of ‘action control’ process with covert 'intention', 'planning' and 'programming' stages and overt execution stage and states that specifying the goal of action, a motor representation could be created and the control action is achieved by comparing the represented goal of the action with the current state of the system. Jeannerod [18] also argues that motor representations participate in cognitive activities in conscious and non-conscious forms. He adds that ‘intended action’ and ‘observation of action performed by others’ could involve both conscious and non-conscious motor representations [27].

2.2 Measurement of MI

Reliable and repeatable measurement methods and tools are essential components for a systematic and sustainable research practice. Despite being an emerging research field, MI research showed that MI is a qualitatively and quantitatively measurable phenomenon with different methods and approaches.

At their study on MI and its measurement, McAvinue and Robertson [27] reviewed different measurement methods of MI depending on types and cognitive activities responsible. Based on the work by Jeannerod [16] [17] [18], they divided motor imageries as 'explicit' and 'implicit' depending on the motor representations being conscious and non-conscious, relatively and reviewed MI measurement methods under these two categories. The main difference between measures of explicit and implicit MI ability was explained by McAvinue and Robertson [27] as the degree of awareness of motor simulation that the participant has when performing the tasks. Summary of this review could be found in Figure 1.

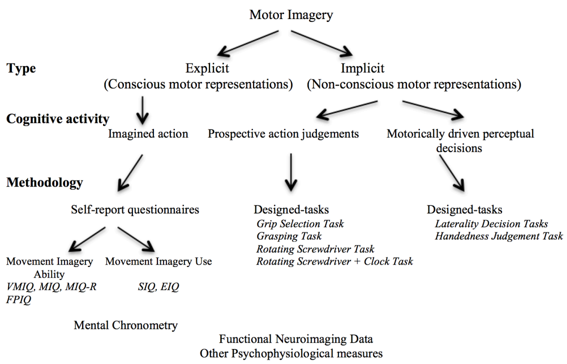

Figure 1. Summary of McAvinue and Robertson' s review study [27] on MI and its measurement.

2.2.1 Self-report Questionnaires

Self-report questionnaires simply measure individual differences of MI in terms of vividness and controllability based on responses to designed questionnaires.

First movement-related imagery questionnaires, Movement Imagery Questionnaire (MIQ) and Vividness of Movement Imagery Questionnaire (VMIQ), were developed by Hall and Pongrac [8] and Isaac et al [15], respectively. There are also other questionnaires measuring use of MI mostly researched on the athletes in sport and exercise such as Sports Imagery Questionnaire (SIQ) [9] and Exercise Imagery Questionnaire (EIQ) [10] as well as questionnaires developed for specific purposes such as Kinesthetic and Visual Imagery Questionnaire (KVIQ) measuring MI vividness developed by Malouin et al [25] for people with physical disabilities and later adapted for elderly subjects [26].

Comprehensive discussions about the questionnaires could be found at various studies such as those by McAvinue and Robertson [27], Collet et al [1] and Lacey and Lawson [22].

2.2.2 Mental Chronometry

Accessing motor images through a chronometric method relies on self-reported reaction times to a given stimuli and durations used to complete a given task. Researchers have been interested in this method mostly to assess individual abilities to preserve the temporal characteristics of the movement during MI [27].

About measurement of implicit MI, McAvinue and Robertson [27] reviewed two configurations; prospective action judgements and motorically driven perceptual decisions.

2.2.3 Measuring Prospective Action Judgements

Research has shown that prospective action judgements use mental simulation of action and various tasks have been designed to investigate the dynamics of prospective action judgements in terms of MI [27].

Johnson [20] investigated the properties of prospective action judgements using the Grip Selection Task. This task required participants to make judgements about how they would grasp a wooden bar, and then they are asked to actually grasp it. Frak et al [6] also used a Grasping Task and asked participants to judge the ergonomic characteristics of grasping and pouring from a container, through certain contact points on the rim of the container [27].

At De'Sperati and Stucchi' s studies [3] [4], participants had to decide whether the screwdriver was screwing or unscrewing after looking a series of motion pictures of a rotating screwdriver, which appeared in different orientations on screen [27].

2.2.4 Motorically driven perceptual decisions

Motorically driven perceptual decisions are decisions made based on use of motor processes. One example task that uses motorically driven perceptual decision is judging the laterality of a visually presented body part. As an example, Parsons [31] [32] [33] showed that the time required to make a handedness judgement about a visually presented hand is proportional to the time required to actually move the hand from its current position into the stimulus orientation and also to the time required to imagine moving the hand from its current position into the stimulus orientation.

2.2.5 Measurement of Neural Activity

Neuroimaging techniques such as functional magnetic resonance imaging (fMRI) are able to gather information about brain activity during MI. They also enable comparison of brain activity during imagined action and executed action as well as strength/weight of different imageries under the same stimuli. Many studies such as Hétu et al [12], Guillot et al [7], Munzert and Zentgraf [30] used fMRI as a valid measurement method of MI and conducted research on MI as well as other forms of imagery and their relationships.

Other methods such as use of electroencephalographic (EEG) and magnetoencephalographic (MEG) were also used to monitor neural activity on real-time basis which appears as an advantage of these techniques compared to neuroimaging techniques [22].

2.2.6 Other Psychophysiological Measures

There is also strong evidence that some psychophysiological parameters change during MI such as cardiovascular responses, electrodermal activity (e.g. heart rate, skin conductance and blood pressure) and electrical activity produced by skeletal muscles measured through electromyography (EMG) [7] [34].

2.3 Fundamental Findings

This section will give significant findings obtained from MI research using above-mentioned methods.

2.3.1 Functional Equivalence between Imagined and Executed Action

It has been shown by many studies that the mental processes responsible for executing an action are also involved when motor imageries about the same action have been created.

Decety and Jeannerod [2] found out that durations of mentally performed and executed action are similar. They showed that this correlation also holds for Fitt' s Law, which describes the fact that there is an inverse relationship between the difficulty of a movement and the speed with which it is performed. In another study by Vandenberg and Kuse [38], participants were given visual targets and told to mentally rotate given objects at a given angle and direction. Results showed that increasing angles of rotation also increased duration of imagined action [16]. These findings suggest that temporal patterns of imagined and executed action are similar and changing difficulties and physical distances also increased duration of imagined action as it happens in executed action.

Besides temporal similarities, there are many studies showing that that similar areas of brain are getting active during imagery and execution through brain mapping techniques such as position emission tomography and functional magnetic resonance imaging [28] [24] [7]. Shaw [34] also found electromyographic increase to be proportional to the amount of imagined effort.

2.3.2 Kinesthetic and Visual Aspects of MI

According to Guillot et al [7], MI may be divided into two different modalities; visual and kinesthetic. Differentiating from visual imagery, he talks about first person (internal) and third person (external) perspectives of visual subscale of MI, where the latter corresponds to visualizing her/his own movements from a spectator point of view, while the former is self-visualization from the moving body. On the other hand, kinesthetic imagery requires one to 'feel the movement' and perceive muscle contractions and stretching mentally.

Guillot et al [7] showed that there is a significant difference in brain activity when VI and KI were compared in terms of active brain areas as well as intensity of these activities. VI activated predominantly the occipital regions and the superior parietal lobules, whereas KI yielded more activity in motor-associated structures and the inferior parietal lobule. Smyth and Waller [35] also provided evidence for the existence of visual, kinesthetic, and spatial aspects of MI, showing that the predominance of each varied with the kind of action being imagined and the situation in which the action was being imagined.

2.3.3 The Relationship between Motor and Auditory Imagery

Hubbard [14] examined the relationship between kinesthetic information and auditory imagery and suggested three ways that nonvocal kinesthetic information in music might influence or contribute to multisensory imagery: formation or activation of action plans, similarities in actual and imagined musical performance and use of imagery in mental practice.

As an example of formation or activation of action plans, Hubbard [14] gave the study of Keller and Koch [21], where they found out in a study that temporal precision in tapping vertical tone keys based on their color increased when tones are arranged according to pitch height. As similarities in actual and imagined musical performance, Haueisen and Knösche' s study [11] was given, showing that when professional pianists listen to piano music, there is a neural activity in the brain as if they themselves were playing piano.

In Highben and Palmer' s [13] study, participants received (a) both auditory and motor feedback, (b) motor but not auditory feedback (silent keyboard), (c) auditory but not motor feedback (fingers held loosely while participants listened to a recording), or (d) neither auditory nor motor feedback. After being exposed to these four configurations, participants were asked to play the piece from memory. Performance was best when both auditory and motor feedback were used during practice and worst when neither auditory nor motor feedback were given. Participants with higher scores on a test of auditory imagery involving memory for melodies were affected less by the lack of auditory feedback during practice.

3. WHAT DOES MOTOR IMAGERY RESEARCH OFFER FOR DMI PRACTICE?

After a short review given before, the main questions of this paper are on the way: In what ways is MI research related to and interesting for DMI practice? How could MI be included in DMI research and practice? In short, as the title of the paper puts, 'What does MI research offer for DMI practice?'

3.1 How is MI research related to DMI practice?

DMI practice, which is based on relationships between action control and sound generation processes using visual and tactile aspects of the interfaces, may benefit from MI research efficiently.

Tactile components of a DMI is intimately connected with kinesthetic, visual and spatial aspects of the instrument and MI research, which enable to systematically study motor processes with all these aspects, could offer a great potential for DMI research.

As given by Jeannerod [17], MI includes all stages of action control process except overt execution and is used as a tool to compare the current state of the system to take the next overt execution stage. So, using MIs to explore the dynamics of action control mechanisms of DMIs in an action-perception cycle could give many information about the control mechanisms of a DMI.

If MI requires a representation of the body as the generator of acting forces as stated by Jeannerod [17], MI, forming mental representations of body action, also offers great potential to explore embodiment process. In his book on Embodied Music Cognition and Mediation Technology, Leman [23] states that human body could be seen as a mediator between mind (musical experience) and matter (sound energy), a biologically designed mediator that transfers physical energy up to a level of action-oriented meanings and to mental level in which experiences, values and intentions form the basic components of music signification. Formation of MIs could be considered as a form of embodiment process where auditory and/or visual matter stimulates formation of mental motor representations without actual motor activity and characteristics of these MIs could be indicators of the embodiment process. Using MI as part of embodiment research and understanding the dynamics of it with other sensory domains within DMI practice may offer great potential for future research.

3.2 How could MI be included in DMI research and practice?

While there have been efforts to create methodologies for evaluation of DMIs, each method creates its own terminology and parameters and it becomes difficult to combine methods and compare results with each other. MI research with its well-established concepts, methodology and literature could offer a new dimension for evaluation of DMIs.

For example, previous MI questionnaires given above could be great guidelines to create MI questionnaires specific for DMIs. These custom-built questionnaires could be used to evaluate DMIs from different perspectives such as interface design, affordance, ergonomics, etc. Also determination of temporal structure of MI created with a given DMI using mental chronometry and comparison of it with that of actual execution times may explore whether temporally consistent motor imageries created with a DMI could yield more efficient interface designs.

MI measurement tools and methods could be benefited not only for evaluating interaction between the performer and instrument, but also communication between performer and audience. For example, vividness measurement of MI of audience during watching a DMI performance may be an effective indicator of the communication between the performer and audience. Future research could reveal how different mapping and interface design strategies may effect vividness of MI of the audience and the dynamics of the DMI design and performance could be explored from this point of view.

The process of mapping is a crucial part of DMI design not only because it determines the relationship between control and sound generation processes but also it establishes the dynamics between auditory and visual/tactile/motor sensory domains. DMI interface designs considering auditory, motor and visual imagery with questions such as 'what kind of sounds would such an interface generate?', 'what kind of motor actions does this interface offer?' or 'how vivid are MIs formed with this interface?' making use of MI research in a systematic approach could yield better results for DMI design and practice.

4. CONCLUSION

MI, which is shown to give significant information about the mental processes of an executed action, is a great resource to explore multisensory processes underlying that action.

This paper gave a short review of MI research with fundamental concepts, common measurement tools and methods, major findings and discussed the potential use of MI research in DMI practice. MI, being the most bodily type of imagery and a key element of action control and embodiment process, is likely to offer a great potential for DMI practice and future studies about DMIs including motor imagery research concepts and methodologies could make a great contribution for design, development and analysis of DMIs.

5. REFERENCES

[1] Collet, C., Guillot, A., Lebon, F., Macintyre, T., Moran, A. Measuring motor imagery using psychometric, behavioral, and psychophysiological tools. Exerc. Sport Sci. Rev., 39, 2, (2011), 85-92.

[2] Decety, J., Jeannerod, M. Mentally simulated movements in virtual reality: Does Fitts's law hold in motor imagery?, Behavioural Brain Research, 72, (1996), 127-134.

[3] De'Sperati, C., Stucchi, N. Recognizing the motion of a graspable object is guided by handedness, Neuroreport, 18, (1997), 2761-2765.

[4] De'Sperati, C., Stucchi, N. Motor imagery and visual event recognition, Experimental Brain Research, 133, (2000), 273-278.

[5] Foxe, J. J., Molholm S. Ten years at the multisensory forum: musings on the evolution of a field, Brain Topography, 21, (2009), 149-154.

[6] Frak, V., Paulignan, Y., Jeannerod, M. Orientation of the opposition axis in mentally simulated grasping, Experimental Brain Research, 136, (2001), 120-127.

[7] Guillot, A., Collet, C., Nguyen, V. A., Malouin, F., Richards, C., Doyon, J. Brain Activity During Visual Versus Kinesthetic Imagery: An fMRI Study, 2009, Human Brain Mapping, 30, (2009), 2157-2172.

[8] Hall, C. R., Pongrac, J. Nevoment Imagery Questionnaire. London, Ontario, Canada: University of Western Ontario, 1983.

[9] Hall, C. R., Mack, D. E., Paivio, A., Hausenblas, H. A. Imagery use by athletes: Development of the Sport Imagery Questionnaire, International Journal of Sport Psychology, 29, (1998), 73-89.

[10] Hausenblas, H. A., Hall, C. R., Rodgers, W. M., Monroe, K. J. Exercise imagery: Its nature and measurement, Journal of Applied Sport Psychology, 11, (1999), 171-180.

[11] Haueisen, J., Knösche, T. R. Involuntary Motor Activity in Pianists Evoked by Music Perception, Journal of Cognitive Neuroscience, 13, 6, (2001), 786–792.

[12] Hétu, S., Gregoire, M., Saimpont, A., Coll, M.-P., Eugene, F., Michon, P. E., Jackson, P. L. The neural network of motor imagery: an ALE meta-analysis. Neurosci. Biobehavioral Review, 37, 5, (2013), 930–949.

[13] Highben, Z., Palmer, C. Effects of auditory and motor mental practice in memorized piano performance, Bulletin of the Council for Research in Music Education, 159, (2004), 58–65.

[14] Hubbard, T. L. Multisensory Aspects of Auditory Imagery, Multisensory Imagery (Lacey, S., Lawson, R. eds.), Springer, New York, 2012.

[15] Isaac, A., Marks, D. F., Russell, D. G. An instrument for assessing imagery of movement: The Vividness of Movement Imagery Questionnaire (VMIQ), Journal of Mental Imagery, 10, (1986), 23-30.

[16] Jeannerod, M. The representing brain: Neural correlates of motor intention and imagery, Behavioral and Brain Sciences, 17, (1994), 187-245.

[17] Jeannerod, M. Mental imagery in the motor context, Neuropsychologia, 3, (1995), 1419-1432.

[18] Jeannerod M. The Cognitive Neuroscience of Action. Oxford, UK: Blackwell Publishers, 1997.

[19] Jeannerod M. Neural simulation of action: A unifying mechanism for motor cognition, NeuroImage, 14, (2001), 103-109.

[20] Johnson, S. H. Thinking ahead: The case for motor imagery in prospective judgements of prehension, Cognition, 74, (2000b), 33-70.

[21] Keller, P. E., Koch, I. The planning and execution of short auditory sequences, Psychonomic Bulletin and Review, 13, (2006), 711–716.

[22] Lacey, S., Lawson R. Multisensory Imagery. Springer, New York, 2012.

[23] Leman, M., Embodied Music Cognition and Mediation Technology, MIT Press, Cambridge, MA, 2008.

[24] Lotze, L., Montoya, P., Erb, M., Hulsmann, E., Flor, H., Klause, U., Birbaumer, N., Grodd, W. Activation of cortical and cerebellar motor areas during executed and imagined hand movements: An fMRI study, Journal of Cognitive Neuroscience, 11, (1999), 491–501.

[25] Malouin, F., Richards, C. L., Jackson, P. L., Lafleur, M. F., Durand, A., Doyon, J. The Kinesthetic and Visual Imagery Questionnaire (KVIQ) for Assessing Motor Imagery in Persons with Physical Disabilities: A Reliability and Construct Validity Study, Journal of Neurologic Physical Therapy, 31, (2007), 20–29.

[26] Malouin, F., Richards, C. L., Durand, A. Normal aging and motor imagery vividness: implications for mental practice training in rehabilitation, Archives of Physical Medicine and Rehabilitation, 91, 7, (2010), 1122-1127.

[27] McAvinue L. P., Robertson I. H. Measuring motor imagery ability: A review, European Journal of Cognitive Psychology, 20, 2, (2008), 232-251

[28] Mellet, E., Petit, L., Mazoyer, B., Denis, M., Tzourio, N. Reopening the mental imagery debate: Lessons from functional anatomy, Neuroimage, 8, (1998), 129–139.

[29] Meyer, G. F., Noppeney U. Multisensory integration: from fundamental principles to translational research. Exp. Brain. Res., 213, (2011), 163-166.

[30] Munzert, J., Zentgraf, K. Motor imagery and its implications for understanding the motor system, Progress in Brain Research, 174, (2009), 219–229.

[31] Parsons, L. M. Imagined spatial transformation of one's body, Journal of Experimental Psychology: General, 116, (1987a), 172-191.

[32] Parsons, L. M. Imagined spatial transformation of one's hands and feet, Cognitive Psychology, 19, (1987b), 178-241.

[33] Parsons, L. M. Temporal and kinematic properties of motor behavior reflected in mentally simulated action. Journal of Experimental Psychology: Human Perception and Performance, 20, (1994), 709-730.

[34] Shaw, W. A. The relation of muscular action potentials to imaginal weight lifting, Archives of Psychology, 35, (1940), 5-50.

[35] Smyth, M. M., Waller, A. Movement imagery in rock climbing: Patterns of interference from visual, spatial and kinesthetic secondary tasks, Applied Cognitive Psychology, 12, (1998), 145-157.

[36] Thomas, N. Encyclopedia of Cognitive Science, 2, (2003), 1147-1153.

[37] Thomas, N. Mental Imagery, The Stanford Encyclopedia of Philosophy, Fall 2014 Edition, Edward N. Zalta (ed.), (2014), accessed on 12.12.2014, URL = http://plato.stanford.edu/archives/fall2014/entries/mental-imagery/.

[38] Vandenberg, S., Kuse, A. R. Mental rotations: a group test of three- dimensional spatial visualization, Perceptual and Motor Skills , 47, 2, (1978), 599-604.