Comparison on brain activity for mechanical imagery and execution: a brief review

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***Abstract*—With this review we summarize the current state of scientific studies in the field of MI (motor imagery) and ME (motor execution). We composed brain map and description which correlate different brain areas with type of movements it is responsible for. That gives a more complete and systematic picture of human brain functionality in a case of ME and MI. Also we found the research gap and possible improvements for the further researches in this field.**

***Index Terms*—Brain activity, Motor imagery, Motor execution, EEG, MEG, fMRI, Transcranial magnetic stimulation, Neurorehabilitation, Brain-computer interface**

I. Introduction

The ability to create and simulate new objects, sensations, and concepts in the mind without any direct effect on the senses is known as imagination. It is a very complex phenomenon, the nature of which is very difficult to study, understand and explain. Publications in scientific journals dedicated to the experimental study of the essence of imagination appeared at the beginning of the 20th century [1]. Since then, thanks to the efforts of cognitive scientists, a rich theoretical framework has evolved that attempts to explain the nature of the imaginary. One important fact obtained by recent imagery researches is distinguishing imagery types by the representation of what a subject tries to reproduce in his/her mind. Such differences exist between visual imagery (VI) and motor imagery (MI, a.k.a. kinesthetic imagery) [2], [3]. Although both of them represent enthralling areas of research, the current review is focusing precisely on the latter type of imagination.

Trying to investigate which theory provide a more plausible explanation for the phenomenon of imaginary movement or provide novel explanation of imagery inner mechanisms, numerous studies have been carried out. This resulted in a huge number of papers on empirical comparisons of ME, MI, VI using different tools (fMRI, EEG, TMS, EMG, MEG) and approaches (behavioral chronometry, connectivity analysis, different statistical approaches). The aim of this review is provide a comprehensive observation on the recent results in the field of imagery movements by grouping all the empirical results achieved by different tools and approaches together and critically assess them to gain a more complete and systematic picture of human brain functionality in a case of ME and MI. These results in better understanding of the nature of imagery movements that could help for future elaborations of motor imagery theories and provide statistically proven description of physiological processes underlying motor imagination as a reference model for future assessment of imagination in modern researches.

II. Research methodology

A. Conducting literature review

A literature review summarizes the state of the art in a subject area by refining the current literature in that field. It is becomes conceivable to find fields where further research will be useful based on this analysis of previous and recent results [4]. For this review, published papers were retrieved in scientific databases using search engines of Google Scholar, Research Gate and Scopus. Initially the following search terms were used in search query construction: ”motor imagery”, ”mental imagery”, ”imagery movements”. After primary search on this terms, in the texts of previously found works there have been conducted cross-checking for omitted terms and formulations plausible for further search queries. A paper was considered relevant for the review if one of the search query or it equivalent reformulation was found in its title, abstract, or keywords.

B. Inclusion criteria

To give a comprehensive picture of the topic, there were applied several criteria to sort out inappropriate in terms of publication type, citation number and other standards results of search. Only primary sources and neither secondary sources nor grey literature were used. However, there were a selection criterion among primary sources too; only published papers and reviews were included. The journal of publication should had impact factor greater than 2.5 at the moment of publication or number of citation should be greater than 100. There was no strict constraint on the year of publication, as EEG- or fMRI-based experiments were available and widely conducting since nineties; and, what is more important, earliest consistent results, which are still mentioned in recent studies, were achieved in these years.

C. Data collection and analysis

After the stage of selection process, there have been conducted data collection process. Although several selected papers contained results for heterogeneous groups due to the experiment design, for this review we extracted only information about control groups, e.g. subjects that are healthy and not trained for MI. Further work on the collected studies led to the decision of the type of analysis. Most of endorsed papers had quantitative method of intervention with homogeneously reported findings. Therefore, as a method for data analysis for finding meta-analysis was chosen. Meta-analysis is a systematic study of the literature on a certain issue that yields a numerical assessment of the impact of a treatment technique or exposure. The comprehensive summarizing of scientific domains that used in meta-analysis has emerged as a more formal, repeatable, and rigorous approach to evidence aggregation.

III. Results

Studying and systematizing collected data to compare MI and ME emerged results represented in table 1 and figure 1. At first glance, the significant overlap of the brain regions responsible for MI and ME is striking. This similarity of brain activation for MI and ME could be explained by belonging to the same motor representation system [5]. But despite the fact that the majority of research in this field being focused on activation sites overlap, a more comprehensive observation indicated significant differences between motor imagery and physical execution.

A. Common sites for MI and ME

Particularly, in the premotor cortex (PMC), the primary motor cortex (M1), the primary (S1) and secondary (S2) somatosensory cortex, the supplementary motor region (SMA), striatum, cerebellas areas, the inferior, superior and frontal parietal lobes, there are overlapping activation sites associated with both motor imagery and physical execution.

B. Specific for MI sites

Although previously described regions are common for both MI and ME, SMA [6], fronto-parietal lobe [7] and left posterior parietal [7] have a stronger activation during motor imagery. Moreover, common for MI and ME striatum have stronger activation particularly in caudate nucleus for MI [8]. Lower activation was observed in M1, and particularly low in S1, S2 and the anterior cerebellar areas [6]. These differences could be explained by the lack of somatosensor input during this type of movements. Particularly for the cerebellum, during MI the modality of involvement signal of the posterior cerebellum depends on the degree of acquisition of motor imagery, e.g. become higher with real motor execution practice. Possible explanation is the lack of sensory input for MI while not having enough practice, and more precise and embodied representation otherwise [9]. And the MI-specific areas mentioned in the reviewed papers are rostral premotor, central sulcus, and frontal gyri [10].

C. Specific for ME sites

Common for motor imagery and execution M1, S1, S2, and cerebellar areas have stronger activation for ME than for MI, and more contralateral position. Common for MI and ME striatum have stronger activation particularly in posterior part of the putamen for ME [8]. Low activation for ME was observed in SMA, posterior and inferior parietal lobes. The ME-specific area mentioned in the reviewed papers is precentral gyri.

Table 1 - Brain areas activated for MI and ME, aggregated articles

Brain Structure	Common for MI and ME	MI	ME
Inferior parietal lobe	[11] [12]	[11] [13] [12]	[11] [12]
Superior parietal lobe	[14] [12] [15]	[14] [13] [12] [15]	[14] [12] [15]
Posterior parietal lobe	[7]	[16] [7] [17]	[7]
Frontal parietal lobe	[8] [5]	[8] [7] [5]	[8] [5]
Prefrontal cortex	[18]	[18]	[8] [18]
Subcortical	[8]	[12] [8]	[8]
Rostral premotor	-	[17] [8]	-
Striatum	[8] [11]	[11] [8] [13] [19] [20]	[11] [8]
Cerebellar areas	[8] [18] [5] [7] [6] [12]	[8] [7] [12] [5]	[14] [8] [11] [13] [6] [7] [20] [12] [7] [15] [6] [5] [8] [18]
M1	[12] [15] [6][21]	[22] [23] [6] [12] [21] [15]	[6] [20] [12] [15] [21] [7] [5] [18] [23] [11]
S1	[6] [15]	[15] [6]	[6] [15] [7] [18] [23]
S2	[24]	[24]	[24]
SMA	[18] [14] [6] [15]	[14] [18] [6] [7] [12] [15] [7]	[14] [6] [15] [5] [18] [11]
PMC	[15] [6]	[6] [15]	[15] [13] [6]
Central sulcus	-	[8]	-
Precentral gyri	-	-	[21]
Frontal gyri	-	[7]	-

IV. Discussion

A. General conclusion

Trying to understand the nature of imagery movements, we performed search through the scientific databases, selected papers by inclusion criteria and used meta-analysis as a method of numerical data analysis. We clustered all the papers by the brain area that was activated during the different type of movements to find the most plausible and frequently observed results on this matter. As a result, we got a brain map of

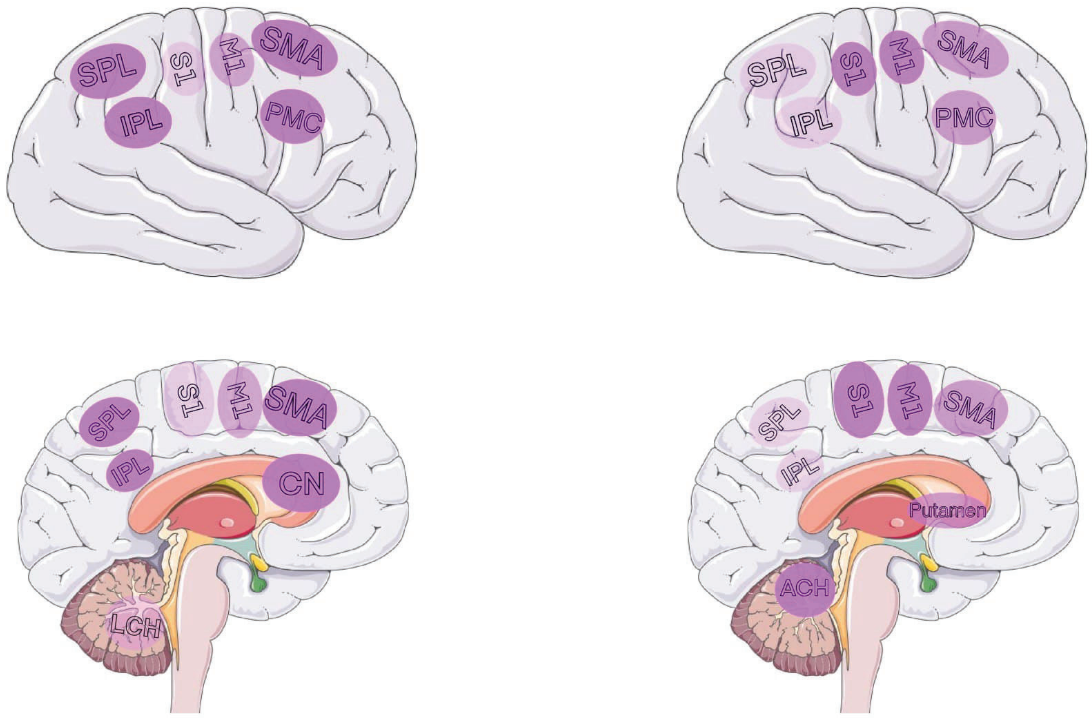

Fig. 1: Activity maps for brain regions during MI and ME
Left - MI brain activation map, right - ME brain activation map

Abbreviations: PMC - premotor cortex, M1 - primary motor cortex, S1, S2 - primary and secondary somatosensory cortices, SMA - supplementrary motor area, CN - caudate nucleus, LCH - lateral cerebellar hemisphere, ACH - anterior cerebellar hemisphere, SPL - superior parietal lobe, IPL -inferior parietal lobe.
The intensity of color depicts the strength of activity in the corresponding region.

different regions in correspondence with 3 cases: only MI, only ME, MI and ME at the same time. These results could help in better understanding of the nature of imagery movements that are useful for future elaborations of motor imagery theories and provide statistically proven description of physiological processes underlying motor imagination as a reference model for future assessment of imagination in new researches. Understanding the nature of the imaginary movement and creating a reference model for future assessment, in turn, could profit in a broad field of research including sports, music, prevention and rehabilitation [25]–[27].

B. Current research gap

One of identified gaps in the field of motor imagery is a lack of emphasis on the individual characteristics of the subjects and experiment conditions. Researchers tend to conduct studies in heterogeneous groups in which little or no regard for factors such as age, dominant hand, current health and mental conditions and motivation. So that, unified or average view of the MI representation is created, which brings a little for use of MI in practical point of view. Thus, more attention should be paid to the context of the experiment from the subject's view. Additional criteria, such as experience with MI and cognitive capacity, should be considered for both recreational and clinical applications. Researchers also need to consider additional aspects, such as physical condition, age and motivation of the subjects. In this way it would be better to gain information about how these aspects affect the success of motor imagery practices.

Another important aspect in MI field that further researches may need to study is objective assessment of imagery ability of subjects. Finding more individualized biomarkers that indicate MI also imply gaining knowledge of features that characterize expertise in MI, which would result in more objective assessment of subject's overall ability to imagine and quality of the process of acquiring imagery skills. Finding it out will make empirical researches in MI more subjective, significantly advance our knowledge of the imagination and provide a basis for new research in MI. One of such possible study that can utilize the knowledge of expertise-specific features is accelerate the process of acquiring imagery ability. This could be done via TMS activation applied on the specific brain sites that responsible for expertise in MI, which would give a chance for pure imagers, which often even are not considered and even weeded out in MI studies, to gain skill in MI and take full advantage of its recreational opportunities.

V. Summary

The review was aimed to generalize studies of different aspects of MI and ME, and we summarized previously group-averaged data. But the main issue that still remains in this field is the absence of a universal criterion of imaginary movement, not averaged within the group, but applicable for each object within it. We might accurately assess effects through heterogeneous areas of endeavour to advance the existing motor imagery practice, accelerate the development process of imagery skills and expand the audience to which the recreational opportunities of MI training will be applicable if we were able to define generalized biomarkers of motor-imagery based learning processes and MI expertise-specific features of brain activation.

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