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Impact on MI-BCI of mental rotation performance variations among students of music, sport and education

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ABSTRACT

The study aimed to improve brain computer interfaces (BCI) usability by focusing on one specific aspect of user performances and cognitives abilities : their performance on spacial abilities particularly on mental rotations (ability to rotate an object mentally). The effect on mental rotation test of a regular sport or music practise or having a scientific / technical education is investigated through three subjects groups, each consisting of 5 males and 5 females students (N=30). They had to solve on 60 trials, the rotations of the stimulus "letter R" on a computer screen with different parameters. The data collected and analyse are the accuracy and the reaction time. The results showed significant better mental rotation performance for music students and an influence of the group on the mental rotation reaction time. Possibilities for future optimizations of the experimental design to explore subjects groups performances are discussed.

Keywords

Mental Rotations, Performances, Brain-Computer Interfaces, Music, Sport, Education, Accuracy, Reaction Time, Cognition, Spacial Abilities

Acknowledgments

My Acknowledgements go to the subjects that participate inthat study and to the people who help me to reach them. Special thank you to Anett and Miriam who put me in touch with some of them.

Originality declaration

The aim of this report is to seek group differences in mental rotations performances through subjects in music, sport and education background by building an experimental task to complete on a computer with the letter R. To my knowledge, it is the first experiment of that kind to built on this group sample.

This report contains the work done by myself, Tallulah GILLIARD.

Number of words : 4422

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Motivation

The **aim** of this research is to know **how is it possible to improve MI-BCI* performances through cognitive abilities ?** To do so, I want to compare, first in a preliminary study, three different subject groups on the way they are comfortable with mental rotations** by collecting results and analysing them.

The research question that will attempt to answer here, **is if there is a significant difference between students in music, sport and education performances in mental rotation tasks** (First part of the study described in this report) and then see the **impact on their performances on MI-BCI tasks**.

This lead the following hypothesis :
H1: There is some user profiles (music or sport or education students) that are better at special ability training (mental rotations)
H2: These same profiles are better at MI-BCI performances.

***MI-BCI** (Mental Imagery based Brain Computer Interfaces) Brain Computer Interfaces are neurotechnologies which enable users to control applications using their brain activity. They are equipped with and EEG headset and asked to perform Mental Imagery tasks. EEG use electrodes to record the electrical activity generated by the neurons. (*see page 6*)
****Mental rotation** is the process or ability to rotate mental representations of two-dimensional and three-dimensional objects (*see page 5*)

1.2 What are Mental Rotations ?

Mental rotation is the process or ability to rotate mental representations of two-dimensional and three-dimensional objects.

In 1971, **Shepard & Metzler** (Shepard, Metzler, 1971 **[17]**) introduced the concept of mental rotation into cognitive science. They presented to their subjects pairs of drawings of three-dimensional, asymmetrical assemblages of cubes. In each pair, the first picture either showed an assemblage identical to that shown on the left or either different. The experimental task is to tell, as quickly as possible if they are similar or mirrored. The hypothesis was that the task would be done by forming a three-dimensional mental image and rotating this object, hypothesis that was confirmed.

At that time, their findings were going in the opposite direction of the Behavioural doctrine that was still popular at that time (as defended by Pavlov, Watson, Skinner, Tolman, Lashley and others) for two main reasons : because here the associative learning dosen't apply and because the behaviourists deny what cannot be observed like consciousness, thoughts, hypothetical thinking, imagination or here mental imagery.

Some specifications have been made since : the holistic solution strategy, regarded as a one step method or assessing the problem as a whole and analytic solution strategy, regarded step by step solution method or breaking the solution into parts. Also, since Shepard and Metzler models, ability to manipulate objects in space has been studied a lot. Their original work of measuring mental rotation of three-dimensional objects from 1971 has been cited over 4000 times and has lived few evolutions : Mental Rotation Test (MRT) by **Vandenberg and Kuse** (Vandenberg, Kuse 1978 **[19]**) (*see appendix*), MRT-A by Peters et al. (1995), VMRT by Foroughi et al. 2015.

1.3 What are Brain Computer Interfaces ?

A **brain computer interface (BCI)** is a hardware and software communication system that enables humans to interact with their surroundings without the involvement of peripheral nerves and muscles, i.e., by using control signals generated from electroencephalographic (EEG) activity. (Jeunet & al., 2015 **[9]**) (Graimann, Allison, and Pfurtscheller, 2010 **[5]**)

The first appearance of a BCI system is made by a Medical researcher in Liverpool (UK), **Richard Caton** (Caton, 1875 **[3]**) in 1878 considered as the pionnrer in this field. He discovered that his dog's brain emit electrical activity.

In 1924, **Hans Berger**, a German Psychiatrist and Neurologist was the first to record electrophysiological activity in a human brain. His researches were leaded by a funny-weird story. One day, he almost died during a cavalry exercise and his sister had the strong feeling that something bad has happened to him. He described that almost paranormal event as a telepathic transmission and became fascinated about the mind and brain activity. He recorded his first human ElectroEncephaloGraph (EEG) but waited 5 years to publish the results (Berger, 1929 **[2]**) because he was doubting too much and his colleagues were really sceptical after the publication. He is now considered as the father of EEG.

In the 1960s, **Joe Kamiya**, Professor of Psychology at the University of California in Berkeley developed the Neurofeedback Paradigme (Kamiya, 1969 **[11]**). The concept of neurofeedback is to learn to control specific brain pattern, in particular those involved in pathologies in order to reach a certain mental state. He recorded alpha waves (brain waves that appears during relaxation states) and worked on brain pathologies.

In his paper "Towards Direct Brain-Computer Communication" published in 1973 (Vidal, 1973 **[20]**), **Jacques Vidal**, Professor of Computer Sciences at the University of California Los Angeles define for the first time in BCI history the words "Brain-Computer Interfaces" to refer to these systems.

Over the last forty years, BCI field have evolved in many ways and exponentially.

Zander and Kothe (Zander, Kothe, 2011 **[21]**) have defined BCIs in 3 main categories : active, reactive and passive BCIs. Active BCIs require the user to intentionally perform tasks to control the system. Two main paradigms exist for active BCIs: Slow Cortical Potential based BCIs (SCP-BCI) and Mental-Imagery based BCIs (MI-BCI).

Mental-imagery based brain-computer interfaces (MI-BCIs) enable users to interact with their environment using their brain-activity alone, by performing mental-imagery tasks like mental rotations.
They were initially designed to improve the quality of life of severely motor-impaired patients (victims of a brain injury that caused locked-in syndrome) by creating ways to communicate with the outside world. For instance it's possible to imagine in your head left-hand movements to make the wheelchair turn left. Then the brain activity is sent to a computer to analyse this information (EPFL wheelchair, 2012 **[22]**) (Millán, 2010 **[12]**).

Unfortunately, they are not so much used outside laboratories due to their lack of reliability, which can be explained by two main reasons :

- The sensors and signal processing algorithms used are very sensitive to data noise.
- The users have difficulties learning to use BCIs. 15 to 30% of users seem unable to control an MI-BCI based system (Allison, Neuper, 2010 **[1]**). To control properly a MI-BCI, the user require specific skills in order to generate a clear and stable model while the tasks are performed.

The POTIOC team at Inria Sud-Ouest studied how to help users improve their MI-BCI Performances and which cognitive factors Impact it (Jeunet & al., 2015 **[9]**) (*see part 1.5 previous work : BCI*)

1.4 Previous Work : Mental Rotations

A link between spatial abilities and motor processes is observed for Moreau et al. (Moreau & al., 2011 **[13]**) where there is a significant link between sports performance activity, sport-specific training and mental rotation abilities and can be improved by sport training (Moreau et al., 2012 **[14]**) or juggling (Jansen & al., 2009 **[7]**). Hoyek et al. Showed that medicine students improved their capacity to learn anatomy by doing mental rotation trainings (Hoyek & al., 2009 **[6]**). Shepard (Shepard, 1978 **[18]**) reports a link between spacial abilities and "creative activities" like art, music but also science or mathematics. Pietsch & Jansen, (Pietsch, Jansen, 2012 **[15]**) showed that sport students like gymnasts (Schmidt, 2016 **[16]**), soccer players (Jansen & al., 2013 **[8]**) and music had faster reaction times to mental rotations than student in "education". They used the Vandenberg MRT (Vandenberg, Kuse 1978 **[19]**) and had 120 subjects that all came from a German university.

1.5 Previous Work : BCI

Friedrich et al. (Friedrich, 2013 **[4]**) showed that users can control BCI, driven by distinct mental tasks, with stable performance over months. Jeunet et al. (Jeunet & al., 2015, 2016 **[9]** **[10]**) showed that mental rotations have a good impact on training and performing BCI tasks. They show the correlation between MI-BCI Performance & Mental Rotation Scores (>> $r = 0.696$ – $p < 0.005$). This lead them to the conclusion that spatial ability training improves users's spatial abilities, which in turn has a positive impact on user's MI-BCI performance.

1.6 Hypotheses

Based on these previous work conclusions, this whole study has the aim to show that sports/music students have significant better performances at BCI tasks due to their better performances in spatial abilities / mental rotations tests. It leads to the following hypotheses:

H1: There is some user profiles (music or sport or education students) that are better at spatial ability training (mental rotations)
H2: These same profiles are better at MI-BCI performances.

This report will focus only on the first hypothesis (H1) on a specific population sample.

2. MATERIAL & METHOD

2.1 Population

The subjects were recruited thanks to messages in chat groups of master students, volleyball players, KTH hallen (gym), band orchestra or directly contacting people that were in the personal environment of the author.

There are 3 groups of subjects

- "music" with more than 3h/week of practise (Pietsch, Jansen, 2012 **[15]**)
- "sport" with more than 5h/week of practise (Pietsch, Jansen, 2012 **[15]**)
- "education" (scientific or engineering studies)

NUMBER OF SUBJECTS	MUSIC		SPORT		EDUCATION	
30	W	M	W	M	W	M
	5	5	5	5	5	5

Table 1 : Population sample repartition

(Note : It was my goal to have equally distributed groups)

To be included in the study, the subjects had to practise more than 5h of sport per week for the sport subjects, 3h of music for the music subjects and be in a master degree level in a scientific field for the education subjects.

2.2 Material

For the data collection I used a test on a computer. The screen was displaying the output information (welcome screen, fixation point and stimuli) and the subject was entering the answers through the keyboard for the input.

2.3 Experimental Design

A java based visual test of rotation of random two-dimensional shapes ("R" shape) is used in that experiment.

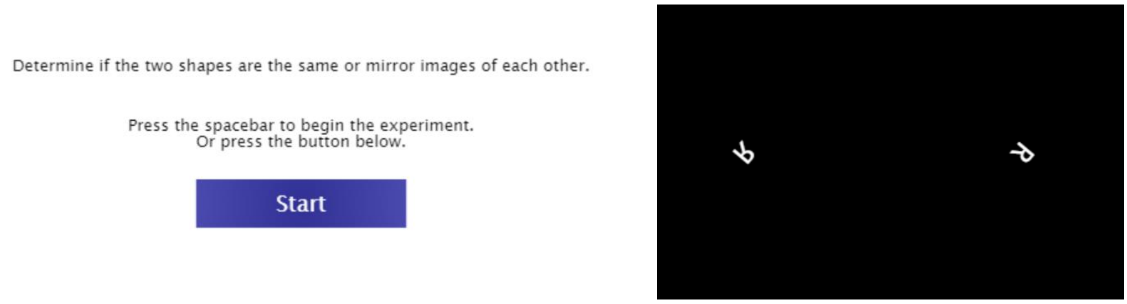


Fig. 1a : Screenshots of the experiment before starting and running

The task is to press "z" for same object and "m" for mirrored object (like in the picture above).

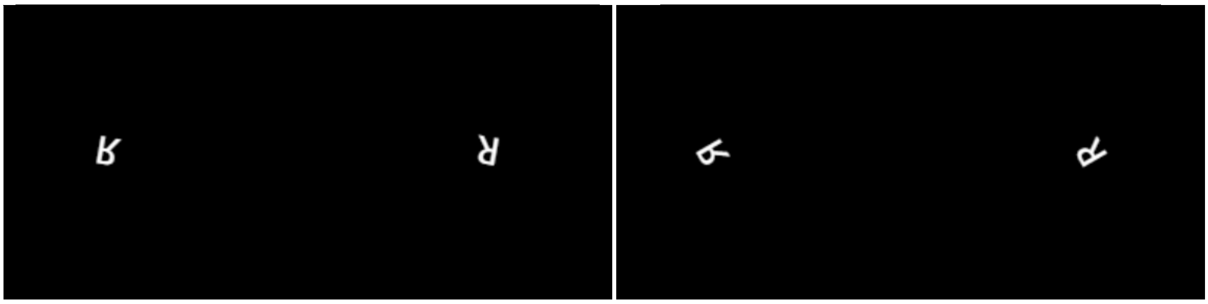


Fig. 1b : example of "mirrored" object

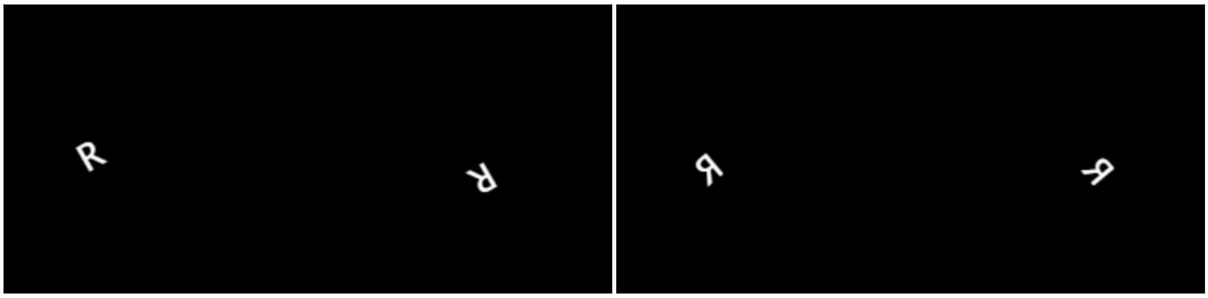


Fig. 1c : example of "same" object

Protocol description :

When the subject arrives and sit in front of the computer, he/she is first ask how many hours of sport or music is he/she doing per week and since how long (questions asked to every subject), just to verify there's no overlapping (for example a subject who would do both a lot of sport and music). Then the difference between “same” and “mirrored” objects and the corresponding keyboard keys to press is explained. The subjects have to try to be fast and to give correct answers. It is always specified that being a research subject is a voluntary choice, and that the subject can choose to stop participating in a research study at any time without giving any reasons. To respect knowledge about data privacy, the subjects are informed of which data will be collected (see below) and used for the study (reaction time, accuracy and group) and that everything will be anonymized. The subjects can be informed of the results of the study if they let me their email address.

The subject results are saved in a .csv file for further analyse. The following informations are saved:

- Participant ID
- Trial (here there are 60 trials for each subject*)
- Number of Rotation Angles (0, 90, 180 in degree)
- Configuration (Mirror or Same)
- Subject Response (Mirror or Same)
- Reaction Time (in milliseconds)
- Response Accuracy (boolean)

* why 60 trials ? : 10 trials*3 different angles(0, 90, 180)*2 same image but flipped = 60

2.4 Pilot Study

Before beginning the real experiment, two KTH students (not included in the study) were tested on the experiment in order to check that the software was running well, that the subjects were clearly understanding and performing the task, and that the data results were in the right format to be analysed. The outcomes of the pilot study confirmed these points. Their results are not included in that study.

2.5 Variables and Factors

The **independent variables (factors)** are the situations : Number of Rotation Angles (0, 90, 180 in degree) or Configuration (Mirror or Same) and the group (Music, Sport, Education).

The **dependent variables (measures)** are Reaction Time (RT in ms) and Accuracy (errors).

2.6 Data Analysis

The data extracted from the mental rotation task is a .csv file. For each subject, there is the detailed results for the 60 trials.

In Excel, data is gathered to have a mean per subject of the values RT and Accuracy, then have a mean per group (Music, Sport, Education) (*see Table 2 and 3*)

3. RESULTS & ANALYSIS

Each subject (N=30), completed the Mental Rotation task. One subject didn't finish the task because he decided to quit before the end, he is not included in the study.

REACTION TIME (MS)	MUSIC	SPORT	EDUCATION
0_SAME_RT (MS)	1128,737066	1722,497567	1704,943828
90_SAME_RT (MS)	1794,802694	2759,100889	1927,009765
180_SAME_RT (MS)	2158,468991	3020,278155	2625,423968
0_MIRROR_RT (MS)	1747,040275	2535,892365	2490,138462
90_ MIRROR _RT (MS)	1802,886627	3108,29619	2298,246119
180_ MIRROR _RT (MS)	2137,455569	3541,096197	2638,448543

Table 2 : Mean results for each 3 groups for the reaction time (RT) in milliseconds according to the different stimuli (Same or Mirror and angles).

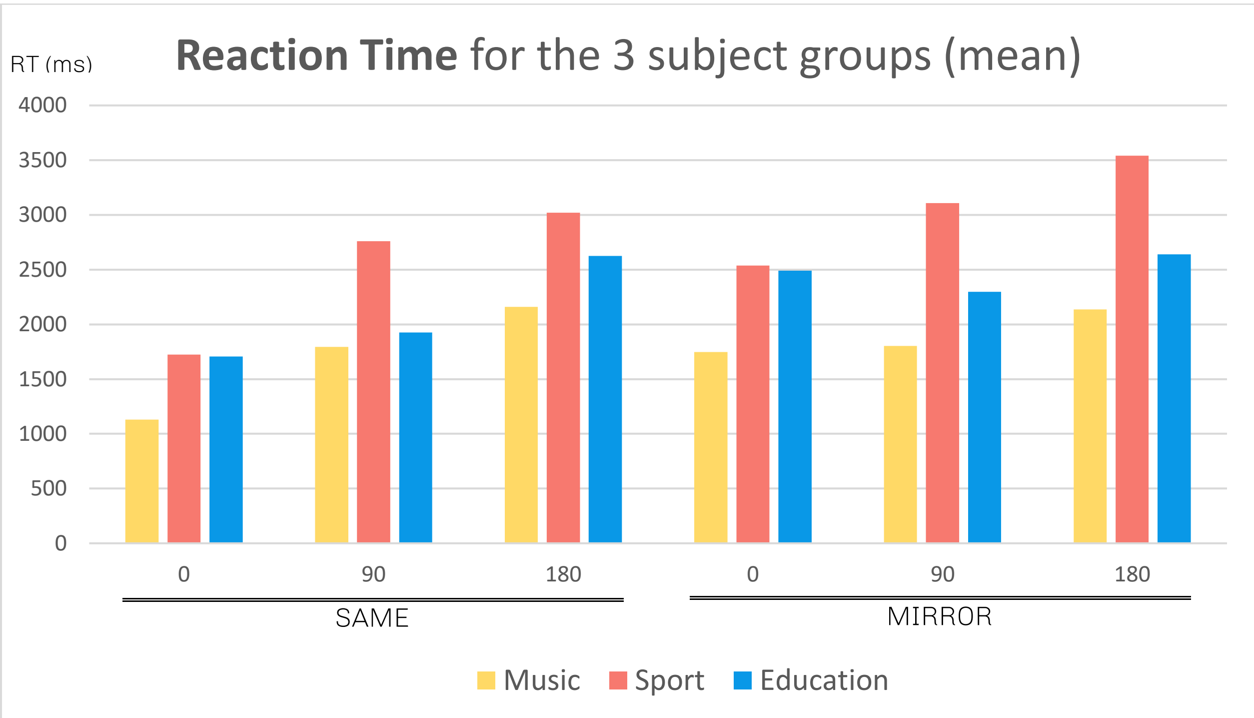


Fig. 2 : Graph for each 3 groups for the reaction time (RT) in milliseconds according to the different stimuli (Same or Mirror and angles).

ACCURACY	MUSIC	SPORT	EDUCATION

0_SAME_ ACCURACY	1	1	0,87
90_SAME_ ACCURACY	0,89	0,93	0,82
180_SAME_ ACCURACY	0,89	0,79	0,8
0_MIRROR_ ACCURACY	0,93	0,92	0,93
90_ MIRROR _ ACCURACY	0,87	0,87	0,91
180_ MIRROR _ ACCURACY	0,92	0,86	0,82

Table 3 : Mean results for each 3 groups for the accuracy according to the different stimuli (Same or Mirror and angles).

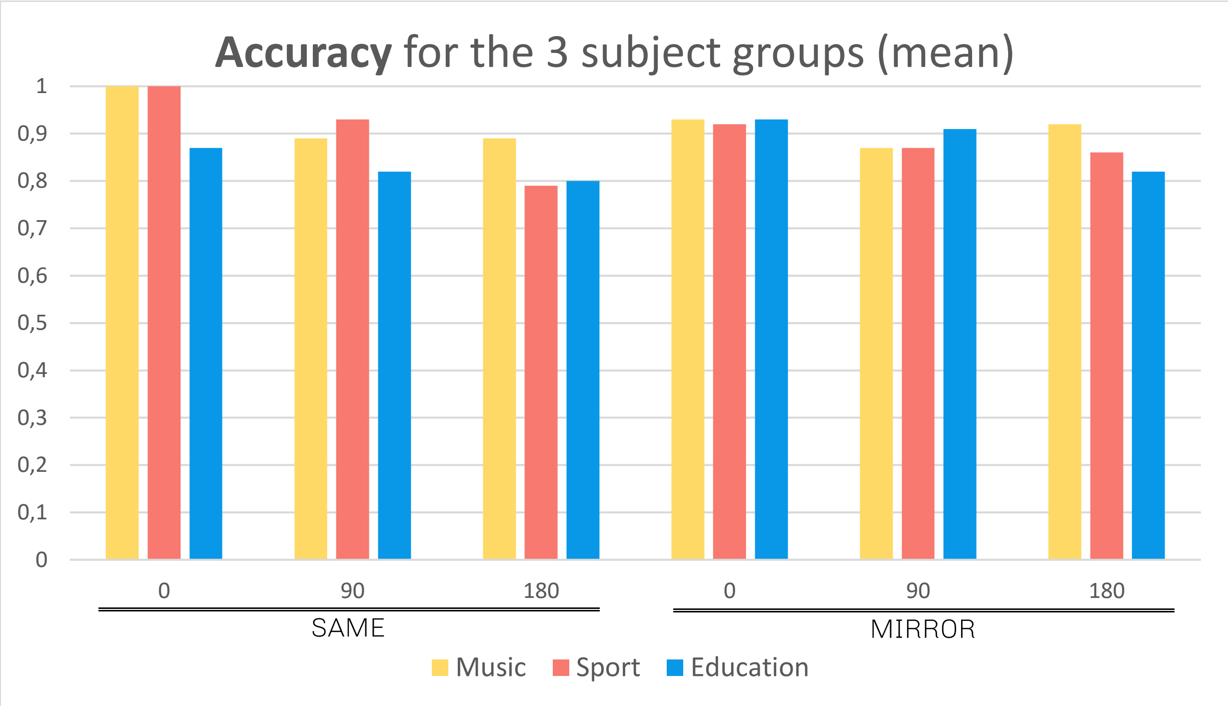


Fig. 3 : Graph for each 3 groups for the accuracy according to the different stimul (Same or Mirror and angles).

Here are some early conclusions based on the visual informations above :

It seems that in any cases the music group have the fastest reaction time with a high accuracy. The music group seems to have the slowest reaction time.

All the groups performed the shortest reaction time and the better accuracy for the situation "Same" and "0° angle" (0_SAME_ RT & 0_SAME_ Accuracy). They seem to have slower reaction time for "Mirror“ situations and for "180° angle" situations.

Analysis of the group influence with ANOVA

I performed an Anova Two-Ways between subjects to study the influence of the different groups. The factors are "group" and the 3 levels are "Music background", "Sport background", "Education/Technical background" and the "angle" with the different situations.

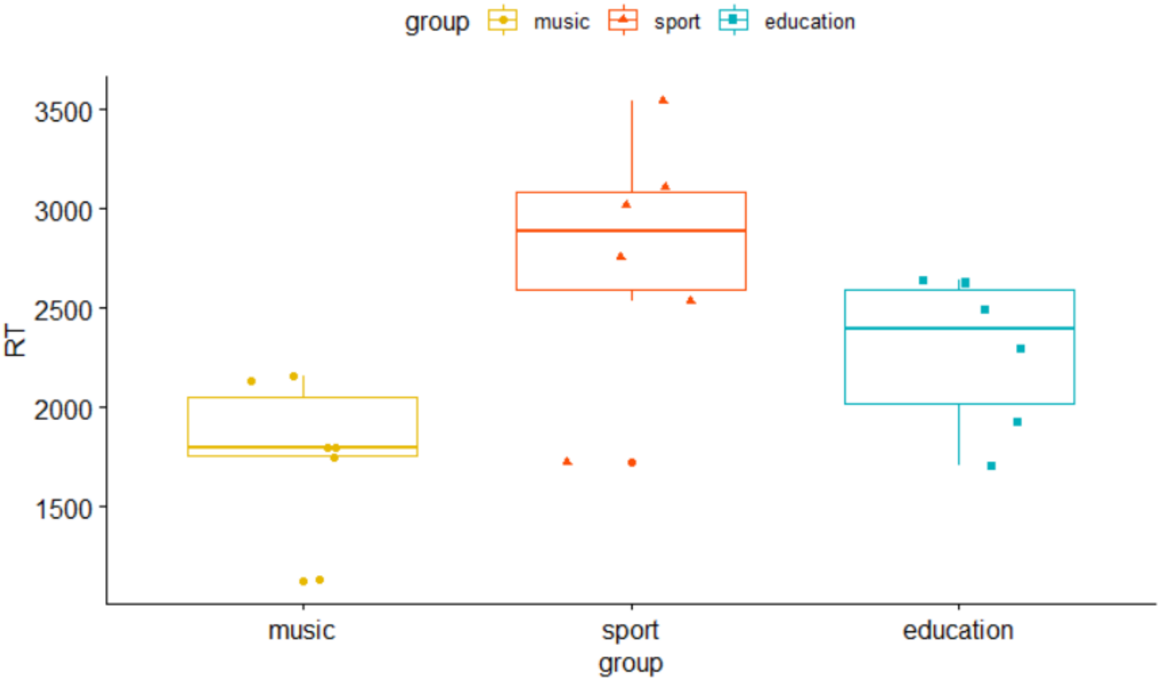


Fig. 4 : Boxplots for each 3 groups for the reaction time (RT) in milliseconds according to the different stimuli (Same or Mirror and angles).

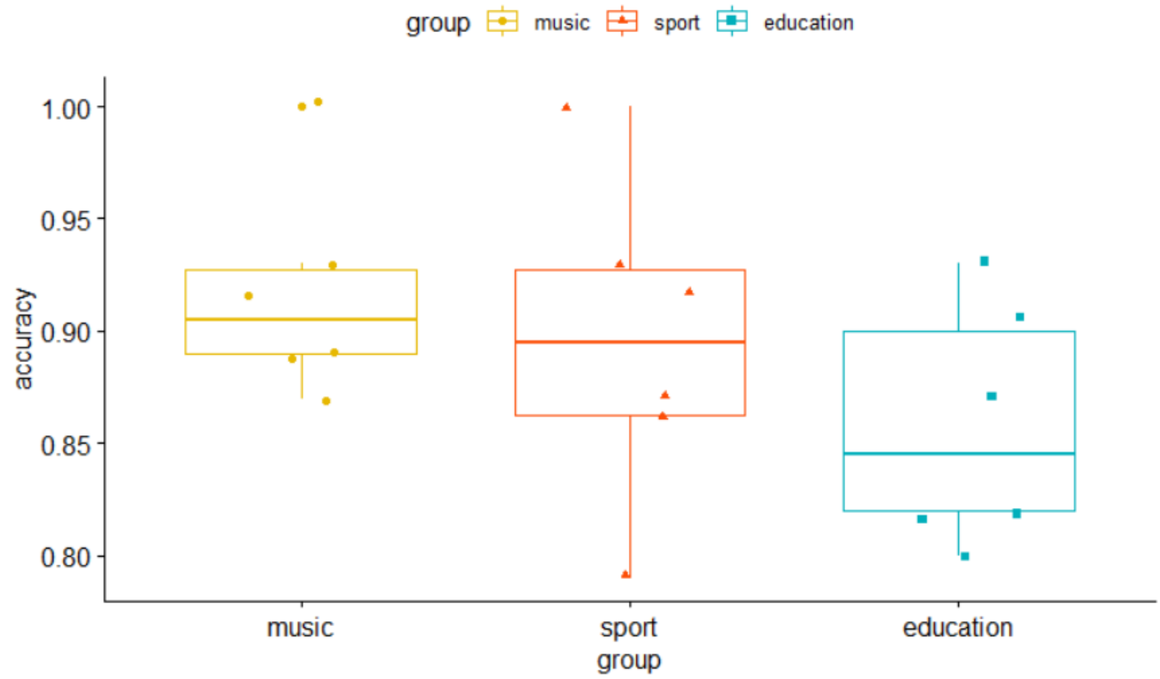


Fig. 5 : Boxplots for each 3 groups for accuracy according to the different stimuli (Same or Mirror and angles).

Visually there is an effect of the group on the reaction time (RT). The "Music" group is the one with the best results (short reaction time and best accuracy). The "Sport" group has the longest reaction time and the "Education" group has the lowest accuracy. The dispersion seems to be really irregular (non-homoscedasticity), it means that the variance of the residuals is not the same so it dosen't respect the Anova linear model hypothesis.

```
            Df  Sum Sq Mean Sq F value   Pr(>F)    
angle        5 2865068  573014   11.43 0.000704 ***
group        2 2918549 1459275   29.11 6.77e-05 ***
Residuals   10  501276   50128                     
```

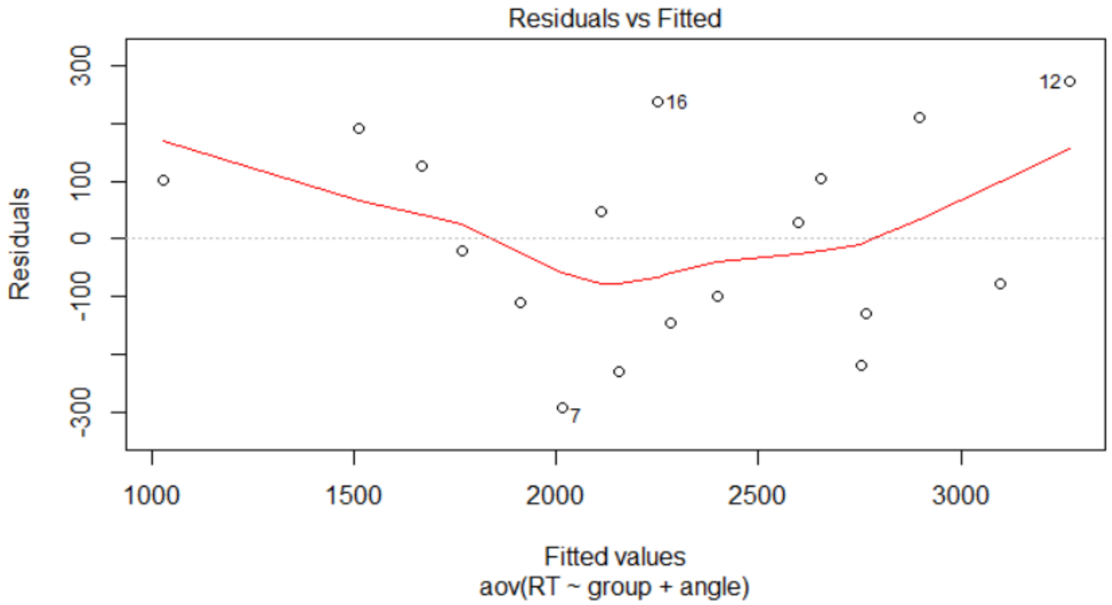
The results of the ANOVA (*Anova results with R in appendix, p22*), seems to show that the variable "angle" and "group" are correlated with the reaction time (RT). The p-value of angle is 0.000704 (significant because $p < 0.05$) and the p-value of group is 6.77e-05 (significant because $p < 0.05$) which indicates that the levels of Reaction Time (RT) are associated with significant different angles and groups.

```
$`group`
                    diff       lwr       upr     p adj
music-education -485.8032 -840.1543 -131.4522 0.0095042
sport-education  500.4918  146.1407  854.8429 0.0079247
sport-music      986.2950  631.9439 1340.6461 0.0000480
```

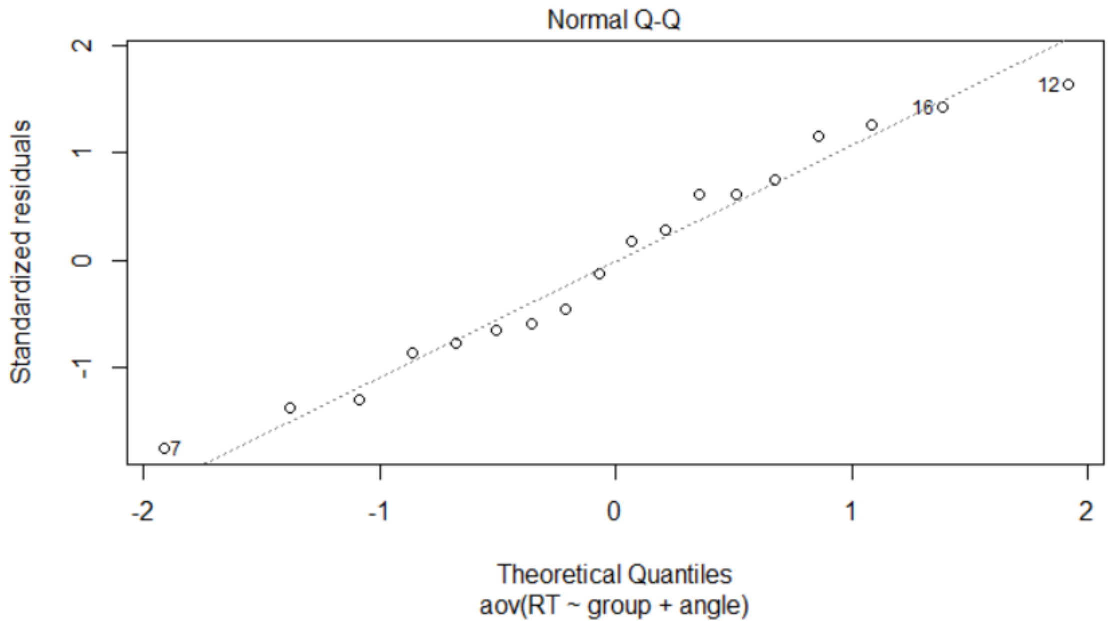
I execute the Tukey Honest Significant Differences (*Tukey HSD results with R in appendix, p22*) for performing multiple pairwise-comparison between the means of groups. "diff" indicates the difference between means of the two groups. "lwr" and upr" indicates the lower and the upper end point of the confidence interval at 95% (default). "p adj" indicates the p-value after adjustment for the multiple comparisons.

The adjusted p-value < 0.05 so it seems to be significant.

To check the ANOVA hypotheses, I look at the residuals versus fits plot for checking the homogeneity of variances. It is supposed to be straight and horizontal.



I look also at the Normality plot of the residuals to verify that the residuals are normally distributed. The quantiles of the residuals are plotted against the quantiles of the normal distribution. It looks correct.



Shapiro-Wilk test (*Shapiro-Wilk results with R in appendix, p22*) on the ANOVA residuals (W = 0.96, p = 0.6) confirms that the normality is correct.

4. DISCUSSION

We saw in the previous section that it seems to be significative effect of the group (music/sport/education) on the performance in Mental Rotation test. In this section, I will interpret and discuss the results described in that previous part.

The main findings of the present study were that the music group outperformed the two other groups of sport and education with their mental rotation performances. There is no significative effect of the sport group outperforming the others and these findings dosen't reflect the existing literature on differences in mental rotation performance between sports groups like gymnasts or athletes (*see part 1.4 Previous Work : Mental Rotations*). Therefore it can be assumed that not all sports (neither all musical activity or all scientific/technical background) will affect mental rotation performance in the same way. In fact, volleyball players obtained slightly better results than gym participants. This could be explored in further experiments. One other reflection is about the order of causation : are subjects already good at Mental Rotation decide to study music/sport to exploit (unconsciously) their abilities, or is it the musical/sport training that will provide them better abilities in Mental Rotations, or both.

Then, one of main limitation of this first part of this study is to have a bias sample. Even if in HCI (Human Computer Interaction), it is quite common to have small samples of subjects (less than 30 participants) every assumption made and based on that sample will have to be considered with precaution and the study must keep a critical point of view on the findings.

Sampling and selection bias: Select patients using rigorous criteria permit avoiding confounding results. Patients should originate from the same general population. Well designed, prospective studies help to avoid selection bias as outcome is unknown at time of enrolment. In this case, I selected the subjects myself through different sources.

The bias in the experiment for the subject can come from:

- An overlapping of the groups (ex : someone from "education" that have been a high level sportive or musician few years ago but dropped because of the studies). It leads to think that the boundaries and selections between the three groups could be improved.

- A misunderstanding of the headlines (too complex or too blurry)
- Not a good performing condition (ex: the subject is tired in the end of the day, stressed or in a rush, or is unfocusing because of ambient noise or external stimulations)
- Potentially environmental factors

Another limitation to this study is that no other personality assessment, cognitive profile assessment, psychological assessment or usability questionnaires were conducted so the external information about the subjects and their background is very poor.

In this study I didn't take in account the factor of gender because I had even group samples of men and women. I also selected groups according the literature. Search for different groups (video game players, architects, PAO engineers, builders, etc) that haven't been tested in any studies, could be interesting for futur research.

Last but not least, regarding the small number of participants, it creates a very small data sample, we can question de relevance of doing such statistical tests on so small populations. The existence of more appropriate or better performed statistical tests is a major key to work on for further research.

In conclusion, if the results and perspectives shown in this preliminary study are confirmed and completed, it could have relevant implications for the world of Brain Computer Interfaces but also sports studies, musicology and psychology. But regarding the limitations and the numerous additional factors that could influence the results of this study, drawing clearer conclusion could only be done by investigating parameters in further studies.

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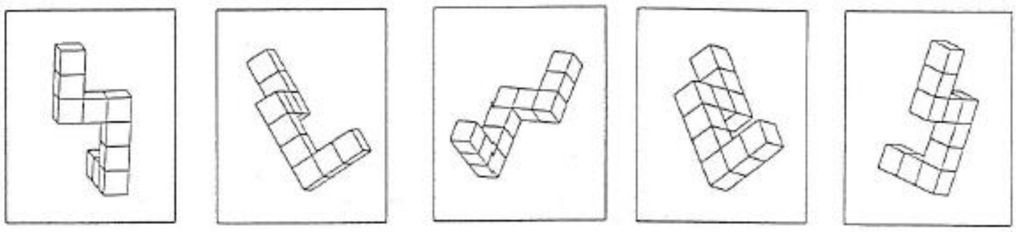
6. APPENDIX

Mental rotation test example (Vandenberg MRT)

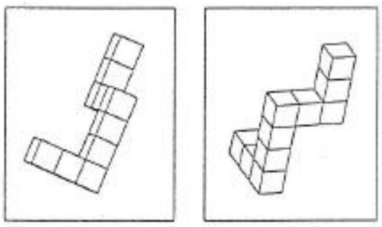
MENTAL ROTATIONS TEST 1

AUTOCAD drawings of Vandenberg & Kuse (1978)* items. Michael Peters, PhD, Dept. Psychology, University of Guelph, Guelph, ON, Canada N1G 2W1

Look at these five figures.



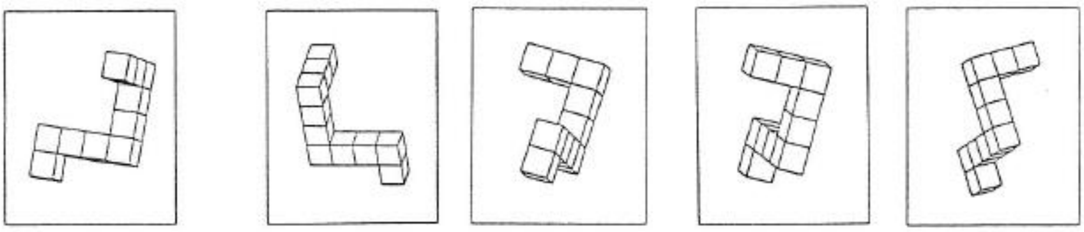
Note that these are all pictures of the same object which is shown from different angles. Try to imagine moving the object (or yourself with respect to the object), as you look from one drawing to the next.



Here are two drawings of a new figure that is different from the one shown in the first 5 drawings. Satisfy yourself that these two drawings show an object that is different and cannot be "rotated" to be identical with the object shown in the first five drawings.

Now look at this object:

Two of these four drawings show the same object. Can you find those two ? Put X's in the lower right corner.



If you marked the first and the third drawings, you made the correct choice.

Results of the ANOVA

```
$`MUSIC`
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
   1129    1759    1799    1795    2054    2158

$SPORT
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
   1722    2592    2890    2781    3086    3541

$EDUCATION
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
   1705    2020    2394    2281    2592    2638
```

a) Mean, Max, Min and Quartiles

```
            Df  Sum Sq Mean Sq F value   Pr(>F)    
angle        5 2865068  573014   11.43 0.000704 ***
group        2 2918549 1459275   29.11 6.77e-05 ***
Residuals   10  501276   50128                     
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

b) Anova results

```
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = RT ~ group + angle, data = res_ReactionTime)

$`group`
                     diff       lwr       upr     p adj
music-education -485.8032 -840.1543 -131.4522 0.0095042
sport-education  500.4918  146.1407  854.8429 0.0079247
sport-music      986.2950  631.9439 1340.6461 0.0000480
```

c) Tukey HSD

```
        Shapiro-Wilk normality test

data:  aov_residuals
W = 0.96094, p-value = 0.6199
```

d) Shapiro-Wilk