# Differences between Mental and Physical Preparation of Muscular Contraction: A Pilot Study

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Abstract: This paper studies some differences between mental and physical preparation of muscular contraction from a signal processing point of view. Mental preparation is a cognitive process prior to performance while physical preparation is a bodily movement produced by skeletal muscles. Two features are selected. The first indicator, called Mean Normalized Preparation Power (MNPP), represents the amount of muscular activity produced during preparation. The second feature, called Normalized Mutual Information (NMI), studies the functional connectivity between a pair of agonist/antagonist muscles entering in action. Results showed that connectivity is more important in Mental Preparation Activity (MPA) than in Physical Preparation Activity (PPA) while muscles power is more important in PPA than in MPA. When classifying the preparation according to muscular activity importance (low and large preparation), previous conclusions are valid for large preparation. In case of small preparation, there is no differences between MPA and PPA in term of MNPP while MPA has higher NMI. Finally, the study of the correlation between MNPP and NMI showed a moderate dependence with the agonist muscle and an independence with the antagonist muscle.

## 1 INTRODUCTION

Finding the best preparation of physical activity is always a daily issue especially during the instants preceding the activity beginning. This activity, called motor preparation (Henry and Rogers, 1960), is useful in many fields like sports and rehabilitation. In sports, some studies showed that motor preparation is effective for performance enhancement in basketball free throw shooting (Lonsdale and Tam, 2008), golf putting (Bell et al., 2010), water polo penalty (Marlow et al., 1998), rugby goal kicking (Jackson and Baker, 2001) and volleyball serving(Lidor and Mayan, 2005). In rehabilitation, one study demonstrated that motor preparation promote the relearning of motor strategies post-stroke on patients with stroke (Malouin et al., 2009). It was also shown beneficial effects in patients with Parkinson's disease especially for reducing bradykinesia (Tamir et al., 2007).

Motor preparation is classified into two types: mental and physical preparation. Physical Preparation Activity (PPA) is defined as any bodily movement produced by skeletal muscles that results in energy expenditure (Caspersen et al., 1985) while Mental Preparation Activity (MPA) is the cognitive rehearsal of a task prior to performance (Driskell et al., 1994).

In this work, we aim studying the differences between these two ways of preparation by considering a handgrip exercise. To study the differences between PPA and MPA, the mean power of preparation activity that appears in EMG signals (Tabar et al., 2017) and the functional connectivity between the two considered muscles during the preparation stage are addressed. The functional connectivity is described through the Normalized Mutual Information (NMI) feature (Arjunan and Kumar, 2015; Kawczyński et al., 2015; Madeleine et al., 2011; Saidane and BenJebara, 2017; Johansen et al., 2013). In a previous work, we showed that the functional connectivity between agonist and antagonist muscles increases during movement's initiation and then decreases during effective contraction (Saidane and BenJebara, 2017). It means that agonist/antagonist muscles put their effort together to initiate the movement. We also showed that when subjects prepare their movement, the intermuscular dependence in greater than the one without preparation at movement's initiation. When dealing



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with preparation power in muscles, we showed in previous work (Saidane and BenJebara, 2016) that preparation occurs in both cases of presence and absence of warning of preparation. When it exists, it is higher when a warning of preparation is given.

In order to enrich previous works, we aim in this work to study the differences between mental and physical preparation. To do it, MPA and PPA are first defined and their percentages of occurence along the experience are announced (section 2). Then, section 3 (resp. 4) analyzes the differences between mental and physical preparation in terms of quantity of preparation expressed using the feature Mean Normalized Preparation Power MNPP (resp. inter-muscular dependence described by Normalized Mutual Information). Section 5 is devoted to the classification of preparation stage into low/large preparation in order to refine the analysis of the differences between MPA and PPA. Finally, the correlation between the two features is given and some concluding remarks are drawn.

## 2 MATERIALS AND METHODS

4 women and 8 men volunteers recruited for this purpose are young people (aged $25.1 \pm 5.9$ years). They were healthy and had no known neurological or neuromuscular disorders at the time of the study and did not take any medication interfering with central nervous system and muscles. Each volunteer executed 15 contractions (5 in self-initiated tasks and 10 in externally-triggered tasks). Hence, a total amount of 180 contractions are studied. In externally-triggered task,tThey were asked to mentally prepare the action during 6.6 seconds and execute the exercice (squeezing a handgrip) during 4.4 seconds, and afterwards rest during 44 seconds. The mental preparation is simulated by a preparation warning (verbal instruction). During this period, they had to firmly motivate themselves and to strongly concentrate on the movement that they had to execute. In self-initiated task, they were also asked to do the same handgrip exercice without mental preparation. Two muscles are considered: the Flexor Digitorum Superficialis (FDS) is the agonist muscle while the Extensor Digitorum Communis (EDC) is the antagonist muscle.

Electromyographic signals were digitized and recorded on a personal computer placed in the control room and equipped with an MP 150 data acquisition system (Biopac MP150, System Inc., Santa Barbara, CA). The system software AcqKnowledge(Version 4.2) was configured to display the EMG signals. Surface EMG signals were recorded using a sampling rate of 1000 Hz during the handgrip preparation and contraction periods from the FDS and EDC muscles of the right arm. The overlying skin was shaved and rubbed with an alcohol wipes to remove dead cells, dirt or skin oils. Bipolar electrodes (ADD208, 8-mm recording diameter) were firmly attached on skin surface overlying each of the two muscles. The muscles were identified by palpating the skin when subjects flexed and extended the fingers. A reference electrode was placed on the skin overlying the lateral epicondyle near the elbow joint of the right arm. The electrode wires were effectively shielded by multiple layers of shielding and connected to the amplifiers (EMG 100C). EMG signal was amplified (gain range at 2000).
Simultaneously with EMG, the force was measured by a pressure captor (hand dynamometer TSD121B-MRI).

## 3 MENTAL VERSUS PHYSICAL PREPARATION

### 3.1 Definition

In order to define MPA and PPA from a signal processing point of view, let's illustrate the FDS muscular activity during the contraction and the time interval preceding it (see Fig. 1). The first case (a) illustrates the absence of preparation and the two others concern the presence of preparation. One can notice a small activity preceding the movement that we qualify as preparatory activity (it was checked and verified that it does not correspond to any kind of noise, interference or crosstalk). Two types of preparation are differentiated. In the first one (Fig. 1.b), the force signal which is acquired simultaneously is equal to zero during preparation. It means that the subject did not apply an action on the grip. We called this activity: controlled or Mental Preparation Activity (MPA). In the second case (Fig. 1.c), the force is different from zero during preparation. It means that the subject unintentionally exerted a pressure on the grip. It is called involuntary or Physical Preparation Activity (PPA).

### 3.2 Preparation Stage in Numbers

To have an idea on when and how much MPA and PPA occurs, the contractions are firstly categorized into two main classes: preparation presence (denoted Yes) and preparation absence (denoted No). Next and in parallel, two kinds of sub-classes are identified: self-initiated/externally-triggered and MPA/PPA (see

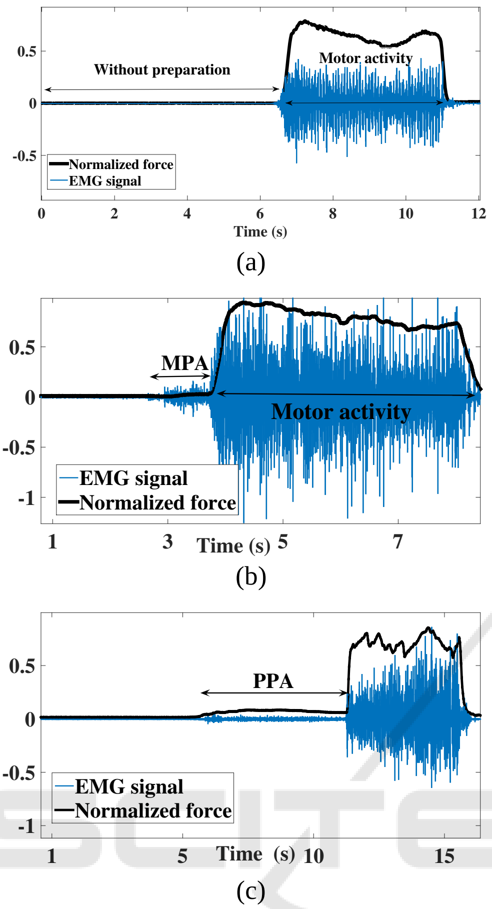



Figure 1: Temporal evolution of EMG and force signals. (a): without preparation, (b): with mental preparation and (c): with physical preparation.

Fig. 2). The first one depends on the use or not of preparation warning to simulate preparation while the second one looks if a muscular preparation occurs or not.

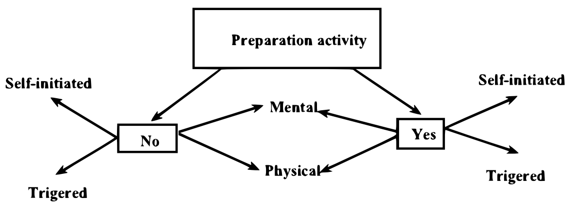



Figure 2: Preparation arboresence.

Tab. 1 resumes the frequency of occurence of the two main classes (with and without preparation) and the frequency of occurence of the sub-classes. Note that each muscle (FDS and EDC) is firstly studied alone and next both muscles are considered together (denoted FDS/EDC). In the last case, both muscles prepare at the same time while the other cases consider each muscle separately without regard to the other (if it prepares or not). One can notice that participants prepare the activity in 70.7% of cases for FDS muscle and 67.85% for EDC muscle. When dealing with preparation mode, one can notice that the percentage of preparation is more important in externally-triggered than in self-initiated for FDS, EDC and FDS/EDC muscles in case of with preparation. When dealing with preparation type, one can notice that the preparation percentage is higher in PPA than MPA when a preparation activity occurs (with). However, we found the opposite result in without preparation case. It confirms that PPA is related to physical preparation while MPA can be considered as a mental preparation. Moreover, results showed that the all percentage are slightly more important for FDS than EDC muscle in the case of ”with” preparation. It can be explained by the fact that FDS is the agonist muscle responsible for of handgrip exercise.

Table 1: Preparation percentages for FDS, EDC and FDS/EDC muscles.

| Preparation | | FDS | EDC | FDS/EDC |
|---|---|---|---|---|
| Yes (%) | Overall | 70.7 | 67.85 | 58.57 |
| | Externally triggered | 54.28 | 48.57 | 43.57 |
| | initiated Self | 16.42 | 19.28 | 15 |
| | MPA | 31.42 | 28.57 | 20.71 |
| | PPA | 39.28 | 38.57 | 37.85 |
| No (%) | Overall | 29.28 | 32.13 | 19.99 |
| | Externally triggered | 20 | 25.71 | 15.71 |
| | Self initiated | 9.28 | 6.42 | 4.28 |
| | MPA | 27.14 | 30 | 18.57 |
| | PPA | 2.14 | 2.8 | 1.42 |

## 4 POWER PREPARATION DURING MPA AND PPA

The objective of this section is to analyze the power during MPA and PPA. The feature characterizing the power is called Mean Normalized Preparation Power (MNPP). It represents the mean of normalized Root Mean Square (RMS). This latter is normalized to 80% of maximal voluntary contraction. In fact, above this level, it was proven that the EMG signal and the force are exceptionally unstable and cannot provide a suitable reference point (De Luca, 1997). We recall that the RMS is a smoothed version of EMG signal during preparation activity. It is obtained as follows:

$$RMS(n) = \sqrt{\frac{1}{N+1}\sum_{k=-N/2}^{N/2} x^2(n+k)}, \quad (1)$$

where $N$ is the window length. Its duration is chosen equal to 512 (the equivalent duration is 512 ms since the sampling frequency is 1 kHz). $x(n)$ is the EMG signal.

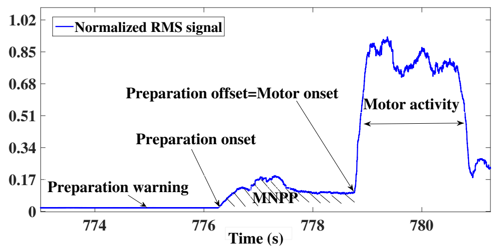
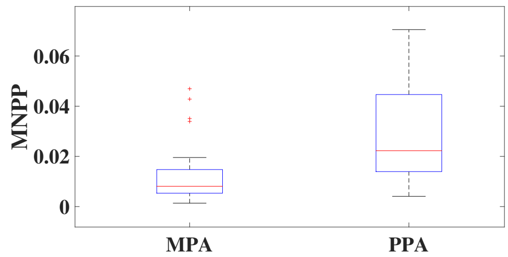



Figure 3: MNPP and the relevant instants illustation on RMS signal.

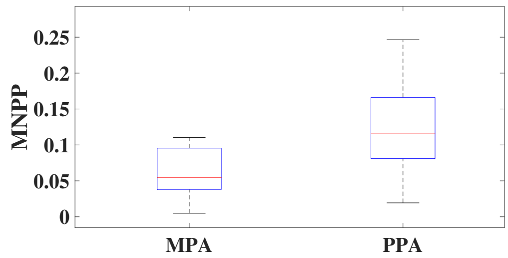
Fig. 3 illustrates the RMS of an example of preparation activity. MNPP is the mean of the hashed region which appears between the preparation onset and the preparation offset. These instants are detected automatically according to the method described in (Ben Jebara, 2015). This graph is enriched with two other instants: the preparation warning instant at which the subject receives the warning instruction in case of externally-triggered and the motor onset is the instant of movement initiation.
Fig. 4 shows the MNPP boxplots during MPA and PPA for FDS and EDC muscles. One can notice that MNPP is more important in PPA than in MPA for both muscles. One way ANalysis Of VAriance (ANOVA) gives a significant difference between the two modes: $P\_value$=0.003 in case of FDS muscle and $P\_value$<0.001 in case of EDC muscle. These results can be explained by the fact that in physical preparation, MNPP is higher because subjects exerced a mechanical reponse (non null force) while the force is null in MPA.

# 5 FUNCTIONAL CONNECTIVITY BETWEEN FDS AND EDC MUSCLES

To study the functional connectivity between FDS and EDC muscles, we used the Normalized Mutual Information (NMI)(Arjunan and Kumar, 2015; Kawczyński et al., 2015; Madeleine et al., 2011; Saidane and BenJebara, 2017; Johansen et al., 2013).




(a)




(b)

Figure 4: MNPP boxplots for FDS muscle (a), EDC muscle (b).

It is calculated during preparation activity starting from preparation onset to preparation offset instant. It is based on the entropy $H$ which measures the uncertainty about an event given probability distribution. It is written as follows:

$$H(X) = -\sum_i P_X(x_i) log(P_X(x_i)), \quad (2)$$

where $P_X(x_i)$ is the probability of the $i^{th}$ outcome of a random variable X. Here, it is an EMG signal observation.
Mutual Information (MI) detects the dependence of FDS and EDC signals. It is defined as follows:

$$MI_{X,Y} = \sum_{ij} P_{X,Y}(x_i,y_j) log(\frac{P_{X,Y}(x_i,y_j)}{P_X(x_i)P_Y(y_j)}), \quad (3)$$

where $P_{X,Y}(x_i,y_j)$ is their joint probability density. The NMI is used to study the functional connectivity between muscles. It is defined as follows:

$$NMI = \frac{MI_{X,Y}}{min(H(X),H(Y))}, \quad (4)$$

where $min$ denotes the minimum of quantities.
Fig. 5 illustrates NMI boxplots during MPA and PPA. From this figure, one can notice that NMI values are more important in MPA than in PPA. Statistical results (ANOVA) show a significant difference between MPA and PPA ($P\_value$=0.003). The fact that NMI is higher in MPA than in PPA means that the intermuscular dependence is more important between the flexor/extensor muscles during mental preparation. This result can be explained by the fact that motor

units are more activated during PPA than MPA because the force is non null and there is a mechanical response in PPA. So, the connectivity does not need to be higher to initiate the action. This result joins another study which demonstrates that the reduction of number of recruited motor units increases the dependency of functional connectivity between the remaining motor units(Arjunan and Kumar, 2015).

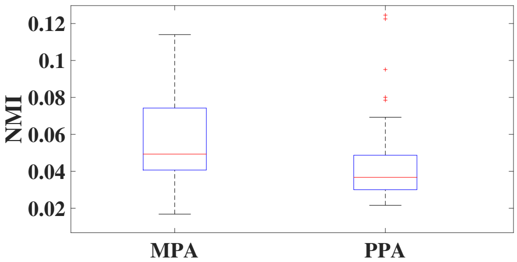



Figure 5: NMI boxplots during MPA and PPA.

# 6 POWER AND NMI ANALYSIS ACCORDING TO LOW AND LARGE PREPARATION

The objective of this section is to study MNPP and NMI differences between MPA and PPA according to preparation importance and the correlation between them.

## 6.1 Classification Process

In a previous work (Saidane and BenJebara, 2016), we found that preparation duration is a pertinent feature to characterize the motor preparation. In this study, we used preparation duration and MNPP features in order to classify the muscular activity during preparation phase according to the quantity of preparation produced. More precisely, we divide preparation activity into low and large preparation. Low preparation has a short duration and a weak power while large preparation is the opposite case.

Supervised classification is used to define low and large preparation for FDS and EDC muscle separately. Tab. 2 shows the repartition of preparation percentage according to low and large preparation for each muscle. For FDS muscle, one can notice that, in PPA type, the percentage of large preparation represents 83.01% of total preparation. In MPA type, low preparation presents 72.41% of total preparation. It is explained by the fact that mental preparation without pressure on the handgrip leads to low muscular activity. However, in physical preparation, exerting a pressure on the hand leads to a relatively high muscular activity.

Dealing with EDC muscle, results are equivalent to those of FDS muscle. The difference is that the percentage of preparation is slightly higher for FDS than EDC muscle.

Table 2: Low/large preparation percentage for FDS and EDC muscles.

| | MPA | | PPA | |
|---|---|---|---|---|
| | Low | Large | Low | Large |
| FDS | 72.41% | 27.59% | 16.99% | 83.01% |
| EDC | 62.06% | 37.94% | 22.65% | 77.35% |

## 6.2 MNPP Boxplots During Low and Large Preparation

After specifying low and large preparation, MNPP is drawn in Low/MPA, Low/PPA, Large/MPA and Large/PPA. Fig. 6 illustrates the MNPP boxplots using the results of the classification of FDS muscle (Fig. 6.a) and EDC muscle (Fig. 6.b).

During low preparation, we show that MNPP values are slightly higher in PPA than in MPA using the two classifications. Statistical tests give no significant difference between MPA and PPA during low preparation (*P_value*=0.231) (resp. *P_value*=0.1253) using FDS (resp. EDC) classification.

Dealing with large preparation which is the case of interest since preparation is meaningful (high level of muscle activity), MNPP is more important in PPA than in MPA in both figures. Statistical results give a significant difference between the two modes: *P_value*=0.039 using the FDS classification and *P_value*= 0.005 using the EDC classification.

Hence, we can conclude that there is no difference between preparing physically or mentally the preparation when the generated muscular activity is weak. However, it is different when the muscular activity is important (large).

This result is useful in rehabilitation. In fact, patient with musculoskeletal disease can replace physical preparation with mental preparation, even though this later is less powerful. This conclusion confirms the ones of other studies which demonstrated that mental preparation can be successfully substituted to physical preparation to improve motor performance(Gentili et al., 2010)(Allami et al., 2008). In fact, Allami *et al.* have found that a combination of extensive mental practice (75% of the training trials) followed by physical practice (25% of the training trials) is sufficient to give similar result as physical practice alone.

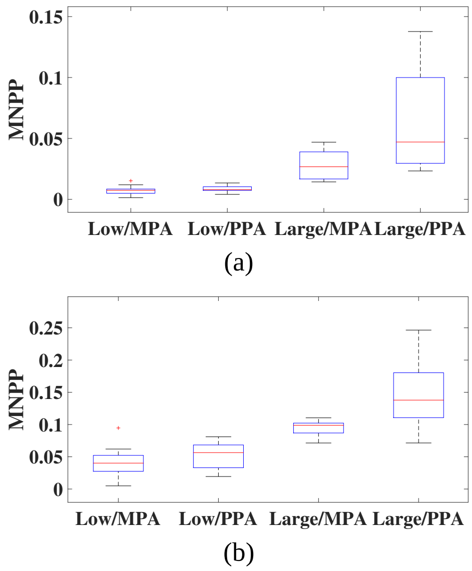



Figure 6: MNPP boxplots using FDS classification (a), EDC classification (b).

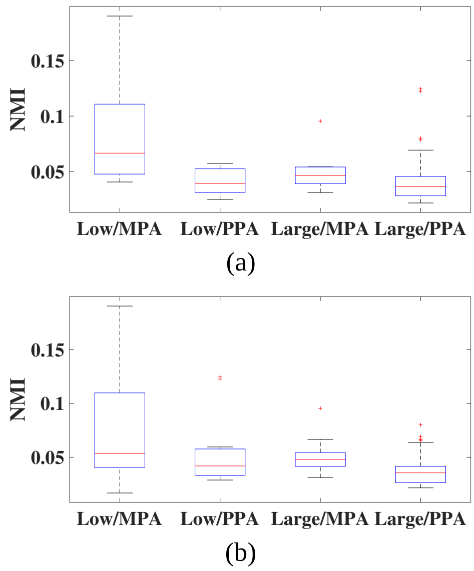



Figure 7: NMI boxplots using (a): FDS classification, (b): EDC classification.

### 6.3 NMI boxplots During Low and Large Preparation

Fig. 7 illustrates NMI boxplots of low/MPA, low/PPA, large/MPA and large/PPA. The two cases are also given according to the used classification. Fig. 7.a (resp. Fig. 7.b) uses the classification of FDS (resp. EDC) preparation activity into low and large. During low preparation, one can notice that NMI is higher in MPA than in PPA. It confirms the results analyzing overall MPA and PPA. Statistical results show a significant difference between MPA and PPA using the FDS classification (*P_value*=0.036). However, there is no difference between the two modes using the EDC classification (*P_value*=0.249). During large preparation, there is no significant difference between two types of preparation (*P_value*=0.4) using the FDS classification while NMI is a discriminant feature between MPA and PPA (*P_value*=0.027) using the EDC classification.

### 6.4 Correlation between NMI and MNPP during MPA and PPA

In this subsection, we aim to study the degree of ressemblance between the two features selected to study the preparation stage. To this end, we used the pearson's correlation coefficient $r$ between NMI and MNPP. Its mathematical expression is as follows (Benesty et al., 2009):

$$r(NMI, MNPP) = \frac{Cov(NMI, MNPP)}{\sigma_{NMI}\sigma_{MNPP}}, \quad (5)$$

where $Cov$ is the covariance between NMI and MNPP. $\sigma_{MNPP}$ and $\sigma_{NMI}$ are the standard deviation of NMI and MNPP respectively. Tab. 3 shows the pearson's correlation coefficient $r$ between NMI and MNPP in case of large preparation only. In fact data leading to low preparation are discarded because of the insignificance of preparation. From this table, we show a very low correlation between the NMI and MNPP for EDC muscle in both MPA and PPA. So, these two features are independent and complementary for analyzing the preparation. In fact, the power of preparation seems to not depend on the functional connectivity since EDC muscle permits to hold the hand, whatever the method of preparation and whatever the degree of connectivity between muscle. Dealing with FDS muscle, results show a moderate correlation in both cases of mental and physical preparation. It means that the two features share a common information. Moreover, this correlation is positive which means that when connectivity increases, the mean power of preparation increases too.

Table 3: correlation coefficients between NMI and MNPP.

| | Large MPA | Large PPA |
|---|---|---|
| FDS | **0.4183** | **0.5555** |
| EDC | -0.0885 | 0.1787 |

# 7 CONCLUSION

This work deals with the mean power and the functional connectivity between FDS and EDC muscles as features to differentiate between mental and physical preparation. Results showed that the increase of functional connectivity of flexor/extensor muscles depends on the mode of preparation. Mental preparation is characterized by an important connectivity and a weak power of muscular activity while physical preparation is characterized by an important power of muscular activity with low connectivity. Finally, a relatively moderated correlation between the mean power and the functional connectivity is observed during large preparation in physical and mental preparation.

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