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**HAVING YOUR CAKE AND EATING IT: FASTER RESPONSES WITH REDUCED
MUSCULAR ACTIVATION WHILE LEARNING A TEMPORAL INTERVAL**

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Abstract

We examined how motor responses to a stimulus evolve as individuals learn to predict when a stimulus will appear, by comparing responses to a regular versus irregular stimulus train. The study was conducted with two groups of adults – one responded to the regular appearance of a visual stimulus every 3s (R group) and the second responded to the irregular presentation of the same stimulus (IR group) at intervals varying between 2 to 4s. Participants responded to the appearance of the stimulus by bending over to press a button that was slightly out of reach. This whole body reach requires muscular activation at the ankles. Over the course of 50 consecutive responses, the response times in the R group were found to decrease more than those for participants in the IR group. The electromyographic (EMGs) of two ankle antagonist muscles, the anterior tibialis and soleus were also modified as participants progressively learnt the temporal regularity of a sequence. Tibialis onset times for the R group were found to decrease faster. A less predictable observation was the faster reduction in post stimulus activation of the tibialis muscle for the R group. Soleus muscle deactivation is an indicator movement preparation. EMG integrals for this muscle a little before stimulus onset showed a trend for greater decrease in the R group. In summary, our study shows that temporal expectations over repeated stimulus presentation permits the dynamic optimization of motor activity with progressively faster response times, muscle activation onset times and lower muscle activation amplitudes.

INTRODUCTION

In this study, we ask how the temporal organization of a stimulus train can alter responses to the stimuli. Such a question is pertinent to real life situations such as work on a factory assembly line, which might involve repetitive motor acts in response to a train of successive stimuli. This situation is in contrast to responses that would take place for a single event such as the arrival of a bus or the boiling of a kettle. The aim of this study is to look into how motor responses and muscular activation evolve over the course of repeated stimulus presentation. In particular how are the responses dynamically altered as a function of the temporal regularity of stimulus presentation?

One good reason to suspect that response dynamics would vary as a function of temporal regularity in a stimulus is a previous study in which we demonstrated that faster response times to *previously unseen* intervals were obtained in groups that had undergone training using temporally regular stimulus trains (Fautrelle et al, 2015). This improvement however was not obtained with groups that had instead been exposed to a temporally irregular stimulus train. The latter result especially shows that the speeding in response times was not due to neuromuscular facilitation (Fautrelle et al, 2015) and that instead, temporal stimulus regularity had led to implicit improvements in timing.

The influence of temporal stimulus properties on motor responses has also been demonstrated in a plethora of studies showing that the length of the delay between two stimuli influence response times to the second stimulus. In these studies a warning cue alerts participants to an upcoming stimulus to which they are expected to respond. The delay between this warning signal and the target stimulus is called the foreperiod. The manner in which the response time varies as a function of the foreperiod is used to study the effects of

temporal expectation. In general, conditions which increase temporal expectancy reduce response times (Woodrow, 1914; Niemi and Näätänen, 1981).

Some of the foreperiod studies have taken the analysis of responses a step further - to non-temporal features of the response movement such as force or muscular activation. Several investigators have reported the use of reduced force for responses occurring after foreperiod delays that permit better temporal prediction (Jaskowski and Verleger, 1993; Mattes and Ulrich, 1997; van der Lubbe et al, 2004). Delving even deeper, into the muscular level, two foreperiod studies report that the interval between EMG onset and the visible mechanical response was shorter with better temporal expectation (Hasbroucq et al, 1995; Tandonnet et al, 2003).

The studies cited above show that response times, response force and muscular activation can be altered by temporal expectation. Indeed several of the neural structures important in interval timing are also very important in motor activity; especially, the basal ganglia and the supplementary motor cortex (Artieda et al, 1992; Meck et al, 2005; Coull et al, 2011). The aforementioned reaction-time studies however did not investigate the dynamics of learning and more importantly, they were done in the context of discrete stimulus presentation following a warning signal. It is not a foregone conclusion that results observed in the discrete reaction time paradigm would also hold for responses to a stimulus train. This is especially true as some researchers have shown that the neural circuits strongly implicated in discrete duration judgments are different from those in which temporal judgments are formed from a train of temporally regular stimuli (Grube et al, 2010; Teki et al, 2011). There is a long history of research on how perception changes as a function of temporal regularity of a stimulus train. For example, it has been shown that target discrimination in the visual (Newhall, 1923; Matthewson et al, 2010; Rohenkohl et al, 2012) or auditory (Jones et al, 1976; Jones and Boltz, 1989) modality is best when targets appear in phase with a temporally

regular stimulus train. Likewise, response times are faster when targets appear at temporally expected moments within a rhythmic or isochronous sequence (Martin et al, 2005; Bolger et al, 2013). In this study, we ask how the temporal regularity of a stimulus sequence would affect not only speed but also muscular activation.

Our investigation on how the nature of a response would change over the course of continuous stimulus presentation was conducted using a type of motor activity called whole body pointing. This consists of leaning over with the trunk to touch or pick up a target which is slightly out of reach. We chose this movement for analysis because it provided two convenient targets for a study investigating temporal anticipation. Flexion at the ankle is an important component when reaching to a target which is slightly out of reach. Both the tibialis anterior and the soleus muscle which are the agonist and antagonist muscles at the ankle joint display changes prior to visible movement onset (Chiovetto et al, 2010; Tolambiya et al, 2012). Furthermore, the soleus displays a pre-movement deactivation which precedes pre-movement activation by the tibialis, thereby providing an opportunity for improving upon previous temporal anticipation studies which focused only on the movement agonist (Hasbroucq et al, 1995, 1997; Tandonnet et al, 2003). The investigation of an agonist-antagonist pair also provides us with the opportunity for looking into a distributed algorithm of motor learning. A final and non-trivial advantage of using this multijoint movement is that it has been very well studied (Pozzo et al, 2002; Berret et al, 2009, Chiovetto et al, 2010, Tolambiya et al, 2011, 2012; Casteran et al, 2013) and would hence provide points of comparison when attempting to understand the effects of temporal expectation.

The soleus and tibialis are two leg muscles which are important for forward propulsion of the body. The hypothesis of the study is that the response times and activation of these muscles, as participants respond to the appearance of a long stimulus train, will evolve differently based on whether the stimuli are presented in a temporally regular or irregular

manner. In keeping with several readiness models that have been proposed in foreperiod studies (Näätänen, 1971; Niemi and Näätänen, 1982, Mattes et al, 1997) we expect that the irregular condition will lead to slower activation times and larger activation amplitudes for the muscles.

METHOD

Thirty healthy participants (16 males and 14 females; mean age =26.9±1.5 years) volunteered for the experiment. There were 7 males and 8 females in the R group and 9 males and 6 females in the IR group. This distribution is not statically different ($\chi^2=0.67$, $p>0.05$). They had normal or corrected-to-normal vision and none had a previous history of neuromuscular or neurological disorders. All the participants were right handed. The experiment conformed to the declaration of Helsinki and informed consent was obtained from all participants according to the protocol of the local ethical committee.

General

The study was conducted by creating two groups of participants. The Regular (R) group was exposed to a temporally regular sequence of 50 consecutive dots while the Irregular (IR) group saw the same number of stimuli presented in a temporally irregular manner. Upon stimulus appearance, the participants responded by leaning over and pressing a button on a table in front of them. They were instructed to respond as soon as they saw the dot. For each participant, there was a sequence of 50 presentations of a stimulus which consisted of a dot on a screen in front of them. For each response, we recorded response times and EMG activity from the soleus and tibialis anterior muscles of the right leg. To encourage

participants to maintain attention during the task and to minimize the use of counting strategies, the participants also carried out a secondary task. This consisted of counting a small proportion of the 50 dots that were green rather than white

Stimulus response protocol

All participants stood at a line marked on the floor 1.5m from the stimulus presentation screen. In order to respond to the appearance of the stimulus on the screen, the participants had to lean over and press a button, which was placed on a table 70cm from the line, while keeping their feet on the line. Stimulus response therefore required that participants involve the trunk in bending over (figure 1).

All participants went through a short familiarization phase in which the experimental protocol was explained to them and they practiced leaning over in response to seven presentations of the white dot. The familiarization phase was followed by the recorded experiment. Each recording session began with a warning cue, comprised of a small red dot, 0.5cm in diameter, presented for a duration of 0.5s on a black background. This was then followed by 50 consecutive presentations of a larger dot, 4cm in diameter, presented for a duration of 0.5s. on a black background. This dot was white on 90% of trials and green on 10% of trials. Participants were told at the start of the trial that they had to count the number of green dots.

Crucially, intervals between dots were fixed at 3s in the R group but varied randomly between 2-4 s in the IR group. The sum total of all interval durations was the same for both groups.

Equipment used

The visual stimuli were projected onto a translucent 2x2 meter screen by a CRT video projector. The spatial resolution of the visual display system was 1024x768 pixels with a vertical refresh sampling rate of 60 Hertz. Subjects responded by leaning over and pressing on a response button.

Electromyographic activity of the tibialis anterior and soleus muscles was measured with pairs of pre-gelled Ag/AgCl surface electrodes (recording diameter 10mm) placed over the muscle belly. The reference electrode was attached on the contralateral patella. EMG activity was recorded with a Biopac MP150 system at a sampling rate of 1000 Hz, bandpass filtered (10Hz to 500Hz) and stored for analysis with commercially available software (AcqKnowledge 4. For MP systems, Biopac System, Santa Barbara, CA). Synchronization of EMG signals with the timing of the visual stimuli and response button presses was also managed by the Biopac MP150 system.

Data analysis

Data analysis was conducted with custom-made programs written in Matlab.

Response time: This was defined as the duration between the onset of the visual stimulus and the moment at which participants pressed the response button (figure 2).

Tibialis onset times: EMG-burst onsets were determined by first creating the cumulative distribution of the rectified, slightly (50-point) smoothed raw EMG signal

(cdf(EMG)). This process helped to highlight big, rapid changes in the EMG time series. We then determined the points at which the slope of this cumulative distribution changed most rapidly from a near-zero value to a maximum value (i.e. the points at which the second derivative of cdf(EMG) is maximized). The location of each of these peaks constituted an EMG-burst onset value. We used the *findpeaks* function in Matlab® to find the location of all of these peaks, thereby identifying all EMG-bursts for each participant. Note that the technique relies on the fact that the differences between the EMG from baseline to abrupt burst are bigger than anywhere else. The validity of this algorithm was confirmed by a visual inspection of onset points. This technique is similar to other derivative based techniques which rely on significant abrupt changes in the time series for onset detection (Bello et al, 2005; Majumdar and Vardhar, 2011).

Muscle activation: All EMG activity was first filtered between 20 and 400 Hz, full wave rectified and then smoothed using an average moving window of 50ms (Konrad 2005). Muscle activation in all cases, was computed by using the EMG integral in a pre-defined window. In the case of the tibialis, this comprised a 200-800ms window just after stimulus onset. The window was set by using visual inspection for all participants and all trials to identify the interval over which post stimulus tibialis activation took place. For the soleus, EMG integrals were computed in a 500ms window just before stimulus onset. This window was chosen according to previous reports of intervals over which anticipatory activity prior to voluntary movement took place (Cheron et al, 1997; Leonard et al, 2009; Kaminski et al, 2001; Tolambiya et al, 2012) as well as allowing for underestimation of interval duration This does not imply that there were responses before stimulus onset (there were none observed). Preparatory EMG activity before movement onset however, can occur without visible movement (Chiovetto et al, 2010; Tolambiya et al, 2012).

Statistics: Progression of any variable over 50 stimulus presentations was done by constructing the regression lines of the variable against stimulus number. The slope of the regression line was used to quantify this evolution. The lines were constructed using Excel. Comparisons of the resulting slopes for the R versus IR groups were conducted with independent t tests. The test was applied after ensuring a normal distribution and homogeneity of variance of the data. Normal distribution was checked using the Kolmogorov-Smirnov and Lilliefors test. Homogeneity of variance was ensured using the Brown-Forsythe test. Results were considered statistically significant if $p < 0.05$. All results are reported as mean \pm standard error of the mean (SEM). Effect size was computed using the Cohen d formula.

RESULTS

Below we report the differences in the responses of subjects in the R and IR groups. No mistakes were made in the counts of green dots amongst the presented white dots hence ensuring a maintained attention throughout the experiment for participants in both groups. Figure 2 presents a sample recording of the stimulus appearance, participant response and the EMGs of the tibialis and soleus muscles. Below, we will analyze the manner in which these recordings changed over the course of 50 presentations for the R and IR group.

Response times

For each individual participant, reaction times (RT) were plotted for each of the 50 consecutive stimulus presentations and the value of the fitted linear regression slope characterized how RT evolved over the course of the presentations. This evolution is

presented in Figure 3. Figure 3A presents the progression for two individuals in each group and in 3B we see the averages for each group. The negative slope value in Figure 3A indicates progressively faster RTs over time, while the positive slopes indicate progressively slower RTs. The slopes of the regression lines were compared between groups and were significantly more negative for the R group than the IR group ($t_{28} = -2.86$, $p=0.008$, $d=1.04$). The mean slope value was negative at -3.01 ± 0.92 ms/presentation for the R group but positive at 0.24 ± 0.15 ms/presentation for the IR group.

Tibialis activation onset times

As for reaction times, tibialis EMG onset times were plotted across the 50 consecutive presentations for each participant. Once again, regression lines were used to characterize how onset times evolved over the experimental session. The mean slope for the R group was more negative (-3.03 ± 0.76 ms/presentation) than that for the IR group (-0.69 ± 0.57 ms/presentation) hence indicating a faster evolution towards a speed up in the onset times of the tibialis for the R group. The difference between the two means was found to be significant ($t_{27} = -2.86$, $p=0.02$, $d=2.75$)

Tibialis activation amplitude

The way in which integrated EMG (EMG_i) values of tibialis muscle activation evolved over the experimental session was measured with regression lines. EMG_i values decreased over the course of 50 responses for many individuals of both groups. However, this progressive decrease (quantified by the comparison of regression line slopes) was significantly greater ($t_{28} = -2.33$, $p=0.027$, $d=0.83$) in the R group (-0.004 ± 0.001 mV-ms) than

the IR group (-0.00013 ± 0.001 mV-ms). Figure 4A presents the evolution with repetitive stimulus presentation for two subjects belonging to the R and IR groups. Figure 4B presents the average for each group.

Soleus activation amplitude

As was done for the tibialis muscle, we compared the evolution of soleus muscle activation EMGi values over consecutive trials for R versus IR groups. Integrals of EMG activity for this muscle were done in a 500ms window before stimulus onset. This was the window of interest as the soleus muscle is known as one that shows deactivating activities before visible movement onset. Greater preparation for stimulus onset would potentially lead to progressively greater deactivation of the muscle before stimulus onset. Once again, many participants from both groups displayed a progressive decrease in pre-stimulus activation, which was quantified by the slope of the regression line. The mean slope for the R group (-0.0033 ± 0.0015 mV-ms/presentation) was more negative than for the IR group (-0.000011 ± 0.00087 mV-ms/presentation). This difference was not statistically significant ($t_{28} = -1.88$, $p=0.069$, $d=0.67$), but showed a tendency for it.

DISCUSSION

The hypothesis of our study was that the dynamics of motor response to a regular stimulus train would not be the same as for an irregular stimulus train. This conjecture was investigated by analyzing how response times and muscular activations evolved with repeated stimulus presentations. Indeed we found that response movements evolved progressively and became more optimized with temporally regular (R), as compared to irregular (IR), stimuli.

Our first observation was that responses became faster more rapidly for the group exposed to temporally regular stimuli. The progression towards lower reaction times was not smooth but, ultimately, led to overall improvements. This was quantified by comparing the slopes of regression lines for response times of each individual over the repeated stimulus presentations of the experimental session (Figures 3A, B). The mean slope for the R group was more negative than for the IR group, indicating that temporal expectancy led to improvements above and beyond those that might be gained through simple motor repetition. Indeed, for the IR group, there were in many cases, even an increase in response time over the session, as shown by a mean positive slope for the group.

The tibialis muscle is a key muscle, important for flexion towards the response button (Figure 1). As we had observed a decrease in reaction times for the R group, we would also expect to see faster onset activities in the muscles producing the response movements. As predicted, onset delay for the activation of this muscle (EMG onset delay) also decreased as response times decreased. The comparison of regression slopes between the R and IR groups showed that the decrease in tibialis onset was faster and greater in the R group, when temporal expectation was possible. This delay between stimulus onset and EMG onset has been referred to in previous studies as the 'premotor time' during which processes preceding motor execution take place. This is in contrast to the 'motor time' which follows and is thought to reflect peripheral motor execution. A previous study by Hasbroucq (Hasbroucq et al, 1995) had reported that temporal predictability altered 'motor time' but did not change 'premotor time'. The previous investigation had been conducted using a discrete stimulus reaction time protocol. In contrast, as we had observed changes in the tibialis onset times with temporal predictability in the current study, our results demonstrate that 'premotor time' can also be manipulated by temporal predictability when used in a stimulus train protocol. Some of the reduction in response times with our stimulus train protocol may therefore have their origins

in earlier processes, in keeping with conclusions drawn by Muller-Gethmann et al (2003). It should be pointed out again that both of these previous studies were conducted using the discrete stimulus reaction time paradigm.

While the progressive shift to earlier tibialis onset times with increasing temporal predictability was not unexpected, the progression towards lower tibialis activation (tibialis EMG_i) was less obvious. One would expect that faster movements are accomplished through the application of greater effort. Indeed classic motor control studies have shown that higher torques and EMG amplitudes accompany faster movements (Hollerbach and Flash, 1982; Corcos et al, 1989; Gottlieb et al, 1989). The progression towards lower tibialis activation with consecutive muscle activation was faster in the case of the R group (Figure 4). In other words temporal predictability allowed for motor learning and better performance optimization. These results are consistent with previous observations that have also shown that the manipulation of the temporal organization of stimulus preparation can alter response force (Mattes and Ulrich, 1997; van der Lubbe et al, 2004) and the nature of EMG response bursts (Tandonnet et al, 2003). These previous studies however were conducted with discrete stimuli presented after a warned foreperiod. The focus of these previous studies was on the effect of foreperiod delays and a direct investigation of the dynamics of learning through a response-by-response analysis was missing.

The results with the antagonist soleus muscle were similar but not as striking. As the first muscle which is altered in the preparation to move, it was an interesting muscle to study in light of our interest in temporal anticipation. Previous investigations have shown that the preparation for movement can be predicted by the deactivation of this muscle (Chiovetto et al, 2010; Tolambiya et al, 2012). Indeed, the integration of pre-stimulus EMGs for this muscle showed a tendency for faster reduction in the R group than the IR group, indicating a tendency for greater anticipation and preparation for movement in the case of the former

group. Several researchers have reported the presence of inhibition in the agonist muscle in cases of temporal preparation (Hasbroucq et al, 1997; Touge et al, 1998). This inhibition is difficult to explain in the light of improved motor performance and has been interpreted as serving to increase the sensitivity of motor structures for forthcoming movement or for preventing untimely movement. The current study shows that this inhibition may not only be restricted to the agonist but also to the antagonist. It is easier to provide an explanation for why temporal expectancy would create inhibition in the extensor soleus muscle. Deactivation in this muscle is necessary to permit forward flexion or bending forward for pressing the response button. Progressive decrements in pre-stimulus activity of this muscle would seem to indicate better preparation for movement in conditions that allow temporal expectancy.

While discussing the details of muscular activations and delays, it is easy to overlook an original aspect of this study. As opposed to previous studies on timing which take into account activities of the end effector (the hand) our investigation has positioned itself at the other end of the body – the tibialis and soleus muscles of the legs. These muscles have traditionally been viewed as having postural roles with their primary function being that of keeping the body in equilibrium under the control of lower brain structures transmitting motor commands via the ventromedial pathway. Hand function on the other hand is thought to be under the control of the motor cortex (Bear et al, 2001; Kandel, 2000). Very few studies have specifically investigated how the postural muscles are modified as a result of the temporal organization of stimuli. Our study shows that temporal expectation may have a distributed effect on the body. While the actual response took place through a hand button press, the reduction in muscular activation with increasing temporal expectation also took place at the ankles. Faster reaction times when standing may therefore be achieved through the combined mechanism of better anticipatory deactivation in the antagonist soleus muscle and faster activation in the agonist tibialis muscle.

In the next two paragraphs, we will present and discuss two models that have been presented to account for response modification as a result of temporal preparation. Both the variable-increment extension of Näätänen's readiness model (Mattes et al, 1997) and the Internal Reference Model (Dyjas et al, 2012) were developed in the context of discrete stimulus presentation studies. Nevertheless they are interesting to study in the context of temporal readiness and we will consider how they might be modified for the current study on evolving dynamics with a stimulus train. Mattes et al (1997) proposed a model to explain how reaction force is modified as a function of temporal expectancy. These researchers extended Näätänen's readiness model (Näätänen, 1971) which was used to account for how reaction time is reduced with higher temporal expectancy. Both models consider reactions in response to a stimulus to be shaped by the distance between motor readiness levels and motor action limit. A greater level of temporal expectation and hence readiness would decrease the distance to the motor action limit and hence decrease response times. Mattes et al (1997) extended the model to provide an explanation for the fluctuations in response forces. According to these researchers, in cases of high motor readiness when a stimulus is expected, only a small force is applied, as the distance between motor readiness levels and motor action limits is also small. On the contrary, when this distance is large, a larger overshooting force is applied, hence providing a possible explanation for the larger forces applied in cases of temporally unpredictable stimuli. We propose another possible explanation for the increase of reaction force in our study using stimulus trains. We suggest that in the face of temporal unpredictability, neuromodulatory influences caused by 'stress' lead to a high level of muscular vigilance and preparation. In these conditions, cortical commands result in a higher muscular activation and contractions. Slower muscular activation times with temporal unpredictability in such a model could perhaps be explained by delayed stimulus perception. This baseline modulation mechanism can only be verified by further studies in which we

monitor the evolution of muscle baseline activity levels as temporal uncertainty increases. Delays in visual perception would have to be studied using an electroencephalogram (EEG).

Another useful model to recall at this point is the Internal Reference Model (IRM) (Dyjas et al, 2012). The model proposes that internal representations of time are continuously updated based on the previously seen interval. More accurately the current estimate is a weighted sum of the first and last seen interval. Our research suggests that this model can be extended in conditions of stimulus train presentation. As opposed to a fixed weight for the previously seen interval, the negative slopes of reaction times and tibialis activation onset of the current study, would suggest that the weight attributed to the last seen interval can in fact increase in time.

In the following sections, we will bring up some shortcomings in this investigation and propose some future studies that should be conducted to address them as well as provide a better understanding of the mechanisms underlying the motor control of temporal readiness.

As stated in the Results section, the differences in the activation of the soleus muscle for the R and IR groups showed a tendency for difference but did not attain the levels necessary for significance. In future studies, we will re-inspect this aspect of temporal anticipation with a protocol which should reduce response variance. Our study placed the target at the same distance for all participants irrespective of their height. This would have induced different levels of effort and anticipative delays (eg short participants may require earlier anticipation and greater effort than taller ones, for a target at the same distance). In future studies, we will place the response button at distances which vary according to participant height (Berret et al, 2009; Chiovetto et al, 2010; Casteran et al, 2013).

A future question to be asked with these neuromuscular modifications is - Where along the chain of neural commands do they take place? Many previous studies have shown that they begin in the motor cortex and hence early in the corticospinal circuit. The studies

that established this used transcranial magnetic stimulation (TMS) and event related potentials (ERP). A good review of the conflicting results in this domain and the studies which have been conducted in attempts to resolve them can be found in Burle et al (2010). Once again, they were all performed using the discrete stimulus warned reaction time protocol. A complete understanding of how response amplitudes are dynamically altered *during* learning as demonstrated in the current study will require that we also probe how the commands at the cortical level are altered using TMS and ERPs. As the latter technique may be more sensitive to the movement of the head that comes from whole body pointing, we may have to switch to responses which consist of a simple button press.

Finally, stimulus responses in this investigation were made using whole body pointing movements towards a target. As a movement that involves several joints and muscles, it provides us with the opportunity to gain insight into a key aspect of neuronal processing which is its parallel nature. It cannot be ruled out that movement optimization was obtained through a more even distribution of force generation and that a lower amplitude of muscle activation in the tibialis muscle was accompanied by greater trunk involvement for forward movement. In other words, it is possible that the progressive decrease seen in the tibialis muscle may have been accompanied by a parallel increase in muscles like the erector spinae which would give the trunk a greater role in stimulus response. In future studies, we should place EMG electrodes on the trunk muscles in order to analyze the evolution of activation in these muscles with temporally regular or irregular stimulus sequences. Another interesting question to ask with a multijoint movement would be – how does coordination or synergy organization change in the face of temporal expectation? A multijoint movement can be performed in an infinite number of ways and the nervous system organizes synergies or correlated body segment displacements for movement (Berret et al, 2009). How are these synergies altered when moving to a regular or irregular stimulus train?

In conclusion this investigation has shown that response times and muscular activation are more likely to decrease when responding to a train of temporally regular than irregular stimulus presentations. While previous research has shown that response forces are modified by temporal expectancy, it was primarily demonstrated using reaction time tasks with discrete stimulus presentations rather than with continuous stimulus trains. Our study with its concentration on the motor modality therefore shows along with previous studies on perception that temporal expectancy when processing information in stimulus trains can optimize the activities of the nervous system. Another original contribution of the study is the demonstration that stimulus temporal organization can alter the response characteristics of postural muscles like the tibialis and soleus muscle hence indicating that motor temporal expectation is distributed.

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FIGURE CAPTIONS

Figure 1: Subject response to stimulus. Participants bent over to press a button in response to the appearance of a dot on the screen. For the R group the dots appeared regularly at intervals of 3 seconds while for the IR group they appeared at irregular intervals varying between 2-4 seconds.

Figure 2: A Copy of recordings taken during experiments. The recordings were done using the AcqKnowledge 4 software of the Biopac MP150 system. For each trial, we recorded

the stimulus, subject button press, soleus and tibialis activations. The antagonist activations of the soleus and tibialis muscles can be seen at play in the recording. Just before tibialis activation for forward bending, there is deactivation of the soleus extensor muscles. Response button press comes significantly later than tibialis activation as the button press was only performed after leaning over to touch the button.

Figure 3: Reaction times. This figure presents the reaction times (RT) of subjects in response to the repeated presentations of stimuli in R and IR conditions. A) Each curve represents the responses of one subject in the group over 50 trials. The regression lines show that response times gradually decrease for the subject in the R group while it increases slightly for the IR subject. B) Average responses over 50 trials for all subjects in each group.

Figure 4: Tibialis EMG_i values. Progression of tibialis EMG_i values with trial. A) Figures traced from two individuals in each group. It shows that activation of the tibialis anterior decreased with repetition of response to the rhythmic stimulus while it did not do so for the subject in the IR condition. B) Average responses over 50 trials for all subjects in each group.

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FIGURE CAPTIONS

Figure 1: Subject response to stimulus. Participants bent over to press a button in response to the appearance of a dot on the screen. For the R group the dots appeared regularly at intervals of 3 seconds while for the IR group they appeared at irregular intervals varying between 2-4 seconds.

Figure 2: A Copy of recordings taken during experiments. The recordings were done using the AcqKnowledge 4 software of the Biopac MP150 system. For each trial, we recorded the stimulus, subject button press, soleus and tibialis activations. The antagonist activations of the soleus and tibialis muscles can be seen at play in the recording. Just before tibialis activation for forward bending, there is deactivation of the soleus extensor muscles. Response button press comes significantly later than tibialis activation as the button press was only performed after leaning over to touch the button.

Figure 3: Reaction times. This figure presents the reaction times (RT) of subjects in response to the repeated presentations of stimuli in R and IR conditions. A) Each curve represents the responses of one subject in the group over 50 trials. The regression lines show that response times gradually decrease for the subject in the R group while it increases slightly for the IR subject. B) Average responses over 50 trials for all subjects in each group.

Figure 4: Tibialis EMG_i values. Progression of tibialis EMG_i values with trial. A) Figures traced from two individuals in each group. It shows that activation of the tibialis anterior decreased with repetition of response to the rhythmic stimulus while it did not do so for the subject in the IR condition. B) Average responses over 50 trials for all subjects in each group.







