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Relating plastic changes of short latency human soleus stretch reflex to changes in task performance induced by training*

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Abstract— **Recent findings in the field of neurophysiology showed that operant conditioning on the human H−Reflex is possible. This leads to many possible clinical applications as well as possible sophisticated training methods for athletes. Although stretch reflexes have been subject to extensive literature, knowledge about the influence of short latency stretch reflexes on task performance is lacking. Within this study an ankle control task was designed where perturbations in the magnitude of functional relevance were applied. Results analyzing angle over time after perturbation confirm previous findings which used to analyze the EMG and force response to ankle perturbations. Further it was found that after training the response to perturbations shifted from initially containing latencies which indicate conscious support by transcortical pathways to latencies which could only origin from unconscious stretch reflex responses. The trend of the short latency response to shift towards the long latency response and to diminish, while pre−defined performance criteria improved, denote a functional relevance of the short latency stretch reflex to task performance. Whereas short latency reflexes have any importance at all or if improvements emerge only out of enhancements in the long latency response future work making use of operant conditioning on the short latency H−Reflex will have to unravel.**

I. INTRODUCTION

Operant conditioning on H−Reflex (HR) might provide a tool make us of spinal plasticity to enhance training methods in sports and rehabilitation. Recent research unrevealed that operant conditioning in human soleus HR is possible [1]. Since the HR is the artificial evoked equivalent of the short latency stretch reflex, a possible powerful tool for enhancing sports training methods or rehabilitation procedures has been found. Since short latency responses contribute mainly to single joint movements, the target to enhance sports performance could be to increase stretch reflex (SR) excitability where strong and well defined movements are required, e.g. a sprinter pushing himself out of the start block. Regarding rehabilitation there have been some encouraging findings in spinal cord injured rats where reflex conditioning could improve walking [2]. In human, operant conditioning in clinical application is subject of ongoing research; however, the influence of spinal cord plasticity to task performance is still not confirmed. Therefore, a better understanding should be desired. For that purpose we have been focusing on the soleus SR response.

The SR results out of a sudden stretch of a muscle which causes the muscle spindles to evoke an electrical potential. As a result, motoneurons in the stretched muscle are stimulated within two different timeframes, the short latency response (M1/SLR) and the middle or late latency response (M2). It is accepted that SLR results out of a monosynaptic spinal circuit whereas the M2 response is more controversially discussed in [3]. On one hand the additional time delay is explained by slower afferent nerves, on the other hand it is believed that the M2 delay is due to a transcortical loop. Even though the M2 response might contain a transcortical loop, both responses can be ruled out to be conscious because of their short response time. This was shown in [4] and [5] examining human wrist and elbow/shoulder stretch reflexes.

Still, research unrevealed many factors influencing the SR and the potential influence of the SR to motor output. It has been shown, that under ischemic conditions which reduced the EMG response of the SR, the motor output in a specific task was significantly influenced [6] and [7]. Although the background EMG was not altered during those trials, the effect of the ischemic condition and the unknown relationship between EMG response and actual force response leave the need for further investigations. Further it was discovered that SR can deliver a substantial torque of up to 20 percent of the MVC [8]. Other findings show, that reflex response depends on task instruction [9], the level of muscle contraction [10], the displacement amplitude [11], the bandwidth of the perturbation signal [12] and the mechanical load [13]. A good review of findings concerning plasticity of spinal circuits is presented in [14].

The combination of current research and HR conditioning might provide insight to the effect of spinal plasticity in task performance. In [15] a correlation between changes in HR and improvement in task performance was found. Subjects were asked to maintain a target speed on a bicycle with randomly changing resistance. Where the control group with constant resistance showed no plasticity in H−Reflex, the subjects with changing resistance showed a decrease in H−Reflex and an increase in task performance. It is not possible to conclude that spinal plasticity actually contributed significantly to task performance improvement since other effects may be solely responsible for the performance enhancement. To show a possible significant contribution of spinal cord plasticity to task improvement, it is hereby proposed to use a similar setup like in [15] but when the performance increase starts to saturate, up and down conditioning of the HR should be applied while subjects still perform the

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task. If there could be seen differences in task performances compared to a control group, the significance of spinal cord plasticity would have been proved. The task in [15] may not be suitable because of the amount of muscles involved in the task. This could lead to compensatory effects which could make discovering significant differences difficult. For this reasons a new task was designed and tested within this study. The setup targets mainly the soleus muscle and to reveal many direct mechanical responses of the SR. To maximize the possibility of discovering a significant change, an ankle control task with visual feedback and perturbations in the magnitude of functional relevance was implemented and tested.

II. METHODS

A. Mechanical Design

The mechanical setup was designed so that subjects were seated in a racing car seat with the thigh of the operating leg parallel to the ground and the knee joint flexed by 45 degrees (see Fig. 1). A pedal inducing torque to the ankle was assured to an axis fixed by bearings. With a potentiometer mounted coaxial to the rotational axis the angle of the pedal relative to the ground was measured. In total four tension springs were armed to the pedal. Two pulling the pedal up and two pulling it down. The spring constants were chosen to be such that the angle between the ground and the pedal was 45 degrees in equilibrium and would produce the desired amount of force when pushed down to 30 degrees. By changing the leverage by which the springs where attached to the pedal the resulting torque could be adjusted. To impose perturbations the lower springs could be released by automatically triggered solenoids. Releasing the lower springs results in a sudden increase of torque forcing the ankle joint to flex. This setup ensures that high torques could be produced and a sudden perturbation to the angle joint could be delivered. Depending on the leverage the torque required to hold an angle of 30 degrees was between 18 and 21 Nm before the release of the lower spring. After the release the needed toque was between 25 and 36 Nm hence a perturbation step of 7 and 14 Nm could be applied. Due to the intrinsic compliance of springs the safety of the patient could be ensured. The angle measurement was recalibrated before each trial to avoid drift in the measured angle induced by the potentiometer.

B. Data Acquisiton and Processing

The angle position was sampled at 5000 Hz with a NI DAQ card 6024E. The sampled data was online processed via the Matlab Data Acquisition Toolbox. The angular position was plotted at 30 Hz providing visual feedback to the participants. The trigger was given according to the below defined rules via Matlab through the NIDAQ output connected to a power source to the solenoids.

C. Task and Instruction Protocols

Nine healthy male subjects performed the experiment. One trial consisted of 20 runs which needed about 30 minutes to be executed. 4 subjects did 5 trials with one day of rest in between trials. One subject did 11 trials over the same period of time, meaning no rest in between trials. 4 subjects performed only the first trial to confirm findings relating to only the first trial. All subjects were instructed to avoid co-contraction of the leg muscles to stiffen the ankle joint since this would add an additional parameter influencing the performance criteria. All subjects were properly instructed and were shown an example before their first run.

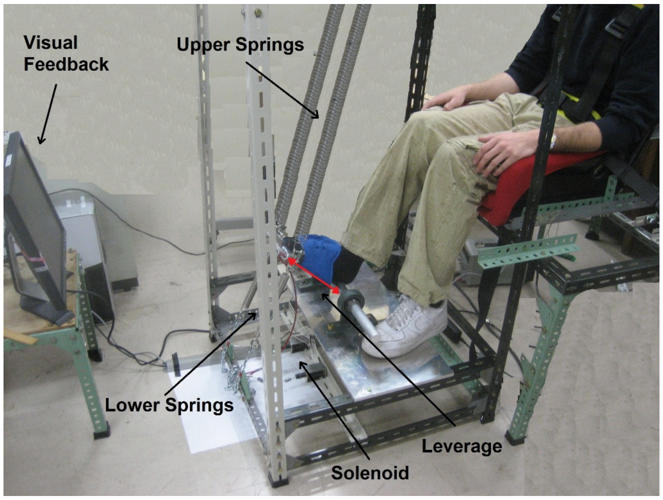

Fig. 1. Experimental Setup

To avoid inter subject variation a MVC run in a isometric setup was performed at an angle of 45 degrees before the experiment (mean=85.7 Nm, std=30 Nm). Depending on the MVC the leverage with which the springs are attached to the pedal was adjusted for each subject.

The task consisted of two parts. First the subject had to push down the pedal to 30 degrees against the increasing torque passively induced by the springs, guided by the visual feedback. Once the angle of the pedal could be maintained within a threshold around 30 degrees for one second, a random time of one to three seconds was triggered. After the elapsing of the random time, the lower springs were released resulting in a sudden increase of torque leading to part two of the task. Participants were asked to minimize the deviation from the desired 30 degrees at all time by counteracting the perturbation torque guided by the visual feedback.

III. RESULTS

In Fig. 2 a typicall response of the very beginning of the training is shown. Noticeable are the little peak in the M1 interval which is believed to originate from the SLR as well as the peak in the M2 interval which is believed to originate from the M2 response of the SR. After the reflex related responses a further increase of the deviation from the desired angle can be observed until finally the ankle is pushed back to the desired position which can be addressed to voluntary control due to the increased latency and the provided visual feedback.

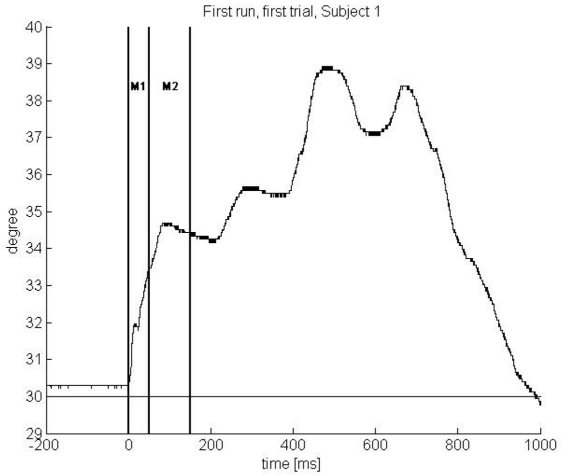

Fig. 2. Response to perturbation from subject 1

In Fig. 3 the response of the same subject but towards the end of the training is shown. The most remarkable change is that the unconscious reflex response is responsible for practically the entire control performance. Due to the short latency of the response, a conscious involvement can be ruled out. In all subjects the conscious contribution like showed in 2 diminished rapidly within the first trials and looked similar to 3. To confirm those findings the 4 subjects which only took the first trail were recruited and confirmed results.

To check whether a change in SLR induced by training can be observed and whether it can be related to task performance, six parameters have been defined which might have the potential to do so. In Fig. 4 those parameters are visualized. The not visualized parameter is defined as the area between the desired angle and the actual angle. This parameter is averaged by the amount of samples so it represents the average deviation from the desired angle after perturbation and hence it is named AvDev. As the peak, always the peak of the M2 response was chosen.

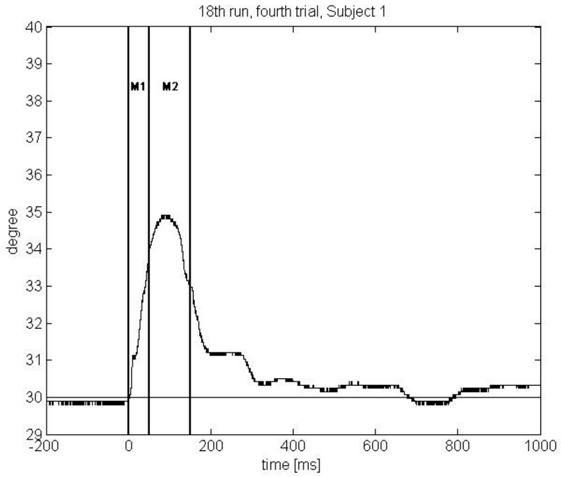

Fig. 3. Response to perturbation from subject 1

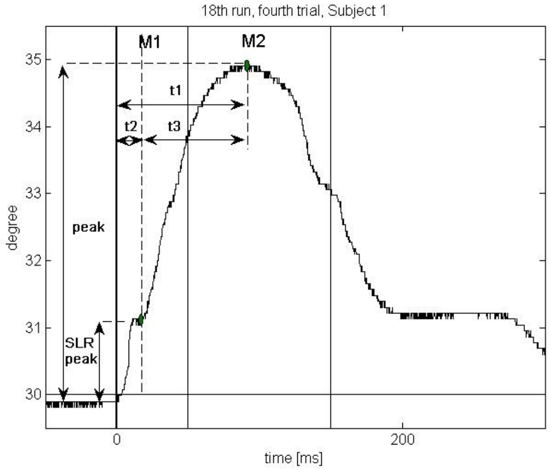

Fig. 4. Visualization of the parameters under observation

For each subject, trial and parameter the mean of the measured values of the 20 runs within a trial was calculated. Those means then were averaged over the different subjects. Hence the presented standard deviation represents the inter subject variation. The results are presented in table 1. Compared are the values of the average of the first and the fifth trials which were averaged over subjects. The p values result out of a two sided t test.

TABLE I

CHANGES OF PERFORMANCE AND REFLEX PARAMETERS AFTER TRAINING

	trial 1	trial 5	p Value
AvDev [°]	0.94 SD 0.19	0.77 SD 0.12	0.067
peak [°]	4.78 SD 2.54	5.52 SD 1.69	0.253
t1 [ms]	86.65 SD 11.41	94.64 SD 13.87	0.171
t2 [ms]	20.21 SD 5.28	22.76 SD 3.76	0.328
t3 [ms]	66.45 SD 6.91	71.88 SD 10.91	0.294
SLRpeak [°]	0.86 SD 0.09	1.30 SD 0.20	0.057

To check if there are any correlations between parameters relating to task performance (peak/AvDev) and the parameters relating to SLR (t2/SLRpeak) the correlation coefficients between those have been calculated and are presented in table 2. Also the correlation between mentioned parameters and the number of trials has been calculated to check possible changes during progress in training. The same averages like in table 1 have been used for the calculation but results of all the trials were used. The parameters t1 and t3 were unaccounted for since they somewhat yield redundant information.

TABLE II

CORRELATIONS BETWEEN PERFORMANCE AND REFLEX PARAMETER

	t2 [ms] 1	SLRpeak [°]	trial
AvDev [°]	-0.94 p=0.02	-0.87 p=0.06	-0.87 p=0.06
peak [°]	0.92 p=0.03	0.83 p=0.08	0.55 p=0.34
trial	0.78 p=0.12	0.76 p=0.13	X

IV. DISCUSSION

As could be expected since it was the main target of the training, the AvDev improves significantly since the goal was to keep the deviation as small as possible.

On the other hand it is surprising that even despite keeping the peak as low as possible results out of the task instructions, the peak actually increased. Since the M2 peak can at most be passively influenced by instructions since the latency is to short to yield voluntary components, a change in the height of the peak might be due to spinal plasticity. The most reasonable interpretation would be that the SLR diminishes which results in a higher peak but allows a better control by the M2 response. This assumption would also be supported by the significantly higher STRpeak which could be explained by a later STR response due to less excitable motoneurons and thus leading to a weaker and or later force response leading to a later and higher peak.

Although the values peak, t1, t2 and t3 do not seem to be significantly altered by the training, they have the trend to increase or decrease. This statement is supported by the high correlation values between the task parameters and the number of trials. The significance of the correlations is not always given despite the high correlation coefficient values due to the small sample size which is limited by the small number of trials. Still, the found correlations between the task parameter values support the above suggested hypothesis. The data obtained by the subject performing 11 trials indicates that there is further changes in parameters beyond the here presented. Due to the different intervals between trails and the fact that only this subject performed additional trials, no quantitative conclusion can be drawn out of this data.

That the peak in M1 results out of SLR and not due to some mechanical property of the mechanical setup is backed up by several observations. The time of occurrence is where one could expect given the literature. Video analysis of the experiment shows no sign of influences of the mechanical setup to the measurements within the relevant time frame. Also the significant difference in the SLRpeak parameter over trials implies that mechanical causes for the peak are unlikely. Since the average over all subjects with different setups regarding applied forces shows a significant difference in the measurements, it is more likely that this emerges out of an adaption of the SLR than due to purely mechanical influences which would be expected to be rather random.

V. CONCLUSIONS

The presented results show the potential of proposed methods to investigate the relation between training induced SLR plasticity and task performance. The results from the testing of the introduced setup have to be interpreted with care. There are mechanical as well as limitations in the conducted protocols which will be mentioned here. This should serve as a suggestion for future work. On the mechanical part there is mainly the improvement that the rotational axis of the actuator devise should be coaxial with the rotational axis of the ankle and not the heel. This would help eliminate compensatory influence by thigh muscles which might have been provoked in the current setup due to induced movements of the knee. Since only averaged values had significant trends, it is assumed that there were several parameters influencing individual runs as well as influencing the performance of a whole trial. The influence of those parameters could possibly be avoided by more rigorous protocols. Of course it would be desirable to examine more subjects over a longer period and take force, EMG and HR measurements as well but unfortunately a single examiner will reach the logistically possible quite soon. Finally the in the introduction proposed method to rule out any other influences to changes than the ones induced by SLR by making use of operant conditioning should be implemented.

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