Ratio of Trials with Passive Kinematics under Fully Relaxed Conditions in Locally Focused Validation Experiments for Human Body Models

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I. INTRODUCTION

Validation of Human Body Models (HBMs) under load generally depends on reference data quality. When relying on allegedly relaxed volunteers reacting passively to external perturbations, it must be assumed that, to an as yet unknown extent, it is not always possible for subjects to comply with required behaviour – see, for example, [1]. To encourage relaxed volunteer performance, kinematic spread in locally focused validation experiments has been shown to narrow when temporal awareness of test start is raised by using a countdown [2]. However, it remains unknown how many trials in a simple setup under subjectively relaxed conditions can be verified as truly passive, i.e. without any notifiable muscle activity, justifying their use as kinematic target for optimising HBM passive properties. Hence, in continuation of kinematic analyses in [2], electromyographic (EMG) data of leg drop pendulum tests have been evaluated. The goal was to quantify peak muscle activity in aware and unaware test conditions and to estimate the ratio of verifiable passive trials to provide insight into data selection processes' influence upon validation target quality.

II. METHODS

Nine male volunteers aged 27±6 years and close to the 50th percentile (1.77±0.02 m, 78±3 kg) participated in a series of leg drop pendulum tests based on [3]. All test procedures were approved by the Ethical Committee of the Medical Faculty of LMU, Munich, Germany. For a detailed description of the test setup, test procedure and preliminary kinematic findings, please refer to [2]. In short, isolated lower leg motion was captured during gravity-induced free swing with a high-speed camera and an EMG at 2000 Hz, recording leg motion and muscle activity of the M. biceps femoris (BF), M. vastus lateralis (VL) and M. rectus femoris (RF). EMG signals were processed including band pass filtering, smoothing and rectification and normalised to maximum voluntary isometric contractions (MVC) as upper boundary. Every subject performed 15 passive knee flexions in total. Following a pre-defined, quasi-random alternating sequence, nine tests commenced after receiving a three-second countdown to test start (aware), while six tests were conducted with a randomly initiated test start within 60 seconds of final preparations (unaware). Volunteers were instructed to relax completely before testing and not to react actively to sudden leg flexion. Early findings suggested a profound reduction of kinematic spread when subjects are aware of test start.

To define trials as truly passive, EMG data were first analysed automatically, using MATLAB to identify onset, offset and peak muscle activity as change points of statistical signal characteristics [4] and then, secondly, by visually double-checking. Peak activity distribution for aware and unaware trials is presented here. If identification of any onset, offset and peak activity was impossible after visual inspection, i.e. signal was equal to pre-test relaxed baseline level as lower boundary, trials were regarded as passive. As one validation target for HBMs, kinematic corridors of Malleolus motion were calculated over the first 500 ms including outliers and extreme values following the method described in [5]. For comparison purposes, three corridors are shown: one including all 135 trials; one with trials without muscle activity in the VL to compare with results from [3]; and one including only those trials without any muscle activity in BF, RF and VL.

III. INITIAL FINDINGS

In total, 135 leg drops were carried out. Presented as boxplots, peak VL and RF median activity were reduced by 4% and 7% MVC, to a level well below 10% MVC, when provided with a countdown, which in turn narrowed the overall span and number of active trials (Fig. 1). BF median activity stayed equal, its total range was hardly affected, and the amount of active trials increased with a countdown. Few outliers (circles) and extreme values

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(stars) occurred. In comparison with reference experiments [3], the share of passive trials, i.e. with "silent" VL disregarding RF and BF, was fivefold in the present study, suggesting 45 trials (~33%) of eight volunteers had been conducted passively, both in aware and unaware conditions. When including EMG signals from RF, VL and BF, the ratio of trials defined passive was reduced further to nine trials (~7%) of three subjects, none of which occurred when a countdown was missing.

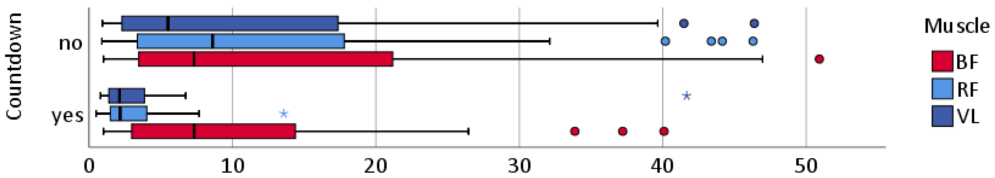

Fig. 1. Peak EMG activity (% MVC) distribution along x-axis of the BF (n=71 aware, n=50 unaware), RF (n=30 aware, n=51 unaware) and VL (n=44 aware, n=46 unaware) muscle for aware and unaware test conditions.

Malleolus' pendulum-like motion in sagittal plane during lower leg drop is plotted in Fig. 2 as kinematic corridors. The mean trajectory is shown by a continuous line flanked by dotted lines as ± one standard deviation (SD) in the x- (vertical) and z-direction (horizontal), respectively, both summed up by the shaded area. In reference to all 135 trials (left), the corridor is narrowed down in both dimensions following [3]'s method (middle), and even more so when including only truly passive behaviour of all relevant muscles (right), while the respective average paths are very similar.

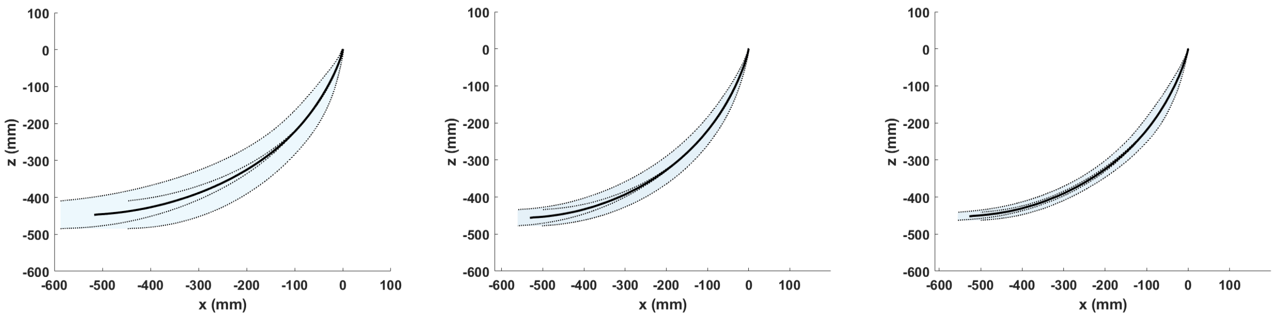

Fig. 2. Kinematic corridor depicting Malleolus average motion (±1 SD) during knee flexion: *left:* unspecified, complete data set, n=135; *middle:* trials without VL activity, n=45; *right:* trials without any muscle activity in VL, RF and BF, n=9.

IV. DISCUSSION

In line with preliminary kinematic findings [2], resisting muscle activity to leg flexion was reduced considerably when volunteers were provided with a countdown as cue for test start. On the contrary, assisting muscle activity did not seem largely affected by temporal (un-)awareness. Considerable M. biceps femoris activity was present in some trials of three particular volunteers; whether these subjects did not understand the experiment thoroughly, simply could not relax the muscle and/or deliberately wanted to support the motion for a presumably good test result is currently being evaluated. As previously assumed, the majority of supposed relaxed trials were not carried out passively, although the ratio of passive trials was much better than assumed in [3]. Although the average path does not seem affected when comparing active to passive data sets, muscle activity had a negative effect on the quality of HBM kinematic validation targets as it leads to a wide range for simulation results to fit in. Further kinematic analyses, including tibia angle time history, are ongoing. Results solely relying on the agonist muscle (here, VL and RF) highlight that disregarding antagonist (here, BF) activity does affect kinematics. Therefore, the authors strongly support measurement of antagonist EMG in future experiments. Given ideal and homogeneous passive conditions, one would expect virtually no deviation from the mean trajectory of motion. By carefully identifying real passive trials this was approximated to the best of our ability, albeit to the disadvantage of data quantity. One possible explanation for the corridor spread could be that it reflects inter-subject differences regarding soft tissue stiffness. In comparison with randomly calculated corridors of the same data size, including corridors with nine samples from one subject, the passive kinematics corridor width does not seem to result from small data size. Thus, to the authors' best knowledge, the study presents, for the first time, passive behaviour that is as close as possible to that of relaxed volunteers, and the most conservative approach to passive HBM validation. In summary, following clearly defined boundary conditions, it is possible to approximate passive behaviour with aware volunteers. Results from fully relaxed experiments should be regarded with caution when used as a basis for passive HBM validation. The selected target kinematics presented here will be used to validate passive HBM behaviour under load, in turn safeguarding isolated muscle controller optimisation for active HBMs.

V. References

[1] Fee, J. W., IEEE, 2002.

[2] Muehlbauer, J., *et al*., IRC-20-26, 2020.

[3] van der Meche, F. G. A., & van Gijn, J., *Brain*, 1986.

[4] Killick, R. J., *Am Stat Assoc*, 2012.

[5] Lessely, D., *et al*., SAE, 2004.