Abstract - Knee joint stability is crucial in human daily activity; however, it is unclear how the central nervous system uses muscle redundancies to create stability. Muscle synergy may be a means by which this control is simplified. These synergies can be extracted using non-negative matrix factorization (NMF). The outputs of this method are finite basis synergies and weight coefficients. We address two major challenges of the NMF approach for extracting muscle synergies on a subject-by-subject basis: repeatability and across subject comparison.

I. INTRODUCTION

Muscle synergies have been extracted by means of non-negative matrix factorization (NMF) in recent studies during static (e.g. [1,2]) and dynamic (e.g. [3,4]) tasks. Muscle synergies can reduce the number of patterns required of the highly redundant motor control system. By reduction of the control space dimension in the complex motor control system, we gain a better understanding of how the central nervous system controls neuromuscular function. With only a few synergies, the aforementioned studies have been able to account for a large variability of the muscle activations in different tasks.

NMF generally will not be convex; therefore, it will result in different local minima depending on the initial guess [5]. The goal of this paper is to study the robustness and repeatability of running NMF on independent subject data obtained from a static weight bearing task.

II. TECHNICAL INFORMATION

The previously reported data of 5 healthy male subjects [6] are used here. Subjects were asked to modulate ground reaction forces to match 12 directionally independent targets set to 30% maximal effort in the transverse plane, while maintaining 50% body weight on the test leg and 30deg knee flexion. EMGs of eight knee joint muscles were recorded.

An NMF solver (alternating least-squares algorithm in MATLAB® [7]) built two matrices such that the Frobenius norm of the error A-CS was minimized, where A (12 by 8), C (12 by n), and S (n by 8) represent the matrices of muscle activation data, coefficients, and muscle synergies, respectively (targets=12; muscles=8; n= number of synergies to be determined) of this static task. The first step is to determine the required number of synergies. For that, the criterion is set to describe the variability of the signal no less than 95%. Therefore a variance accounted for (VAF) is calculated for each subject data independently. To investigate the robustness of results, NMF is run twice using the same settings, which are function tolerance 1e-6, search tolerance 1e-6, and number of factorization replicates 30.

II. RESULTS AND DISCUSSION

The subject-by-subject VAF analysis showed that four synergies will account for 95% variability of the original EMG signals in all 5 participants, as depicted in Figure I.

Figure II shows the results of synergies and coefficients for two runs of NMF. At first glance, the results for the same subjects and data vary greatly from one run to another. However, closer evaluation reveals that some of the columns (synergy indices) are simply switched; for instance, P1/C1 (solid line in top left plot of Figure IIb from run 1 is almost identical to P1/C2 from the second run. This is a common issue with NMF analysis when conducting multiple runs on the same data, which is due to the multiple local minima that the problem has.

If the goal is to compare results of two runs of NMF on one participant data (i.e. the repeatability of NMF outputs) it is challenging as there are two variables C and S and the involved errors are split. In addition, the synergies and coefficients might switch order, which makes the comparison even more cumbersome. Although Kristiansen et al. 2013 discussed the latter issue in brief, and resolved it by visually fixing the synergy sequence swap, we believe that this post-processing would not be a generally effective strategy in different movements: in across subject comparison, it is more challenging to recognize if the differences between two synergies are because of the order switch, actual synergy differences, or an unknown combination of both.

Similarly, if the goal is to compare the outputs across subjects, any observable differences are split into both C and S variables in an unknown way. In case the visual, or even automatic post-process of fixing the order strategy, does not seem obvious (i.e. synergies are not quite distinct), there is a chance of choosing incorrectly. Therefore, there should be a strategy to reconfigure the columns so that functional between subject/group comparisons can be made.

One possible approach is to make this post-processing phase automatic and objective. We suggest a selection algorithm that automatically sets one of the subject’s results as reference and adjusts the sequence of other participant’s outputs based on minimizing the
sum of squared error of synergies and coefficients to find the best column of synergies and coefficients matching the shape of the corresponding reference signals. This should be done by searching all four coefficients and synergies at the same time. A limitation of this approach is that since NMF is prone to change in different runs, and possibly gets stuck in a different local minimum, setting one participant as a reference might not work for a general case.

### III. CONCLUSION

Two major challenges of using NMF approach for subject-by-subject synergy extraction were discussed.

We propose an alternative strategy to run NMF and acquire more robust synergies and coefficients in the prospective publication.

### IV. REFERENCES


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![Figure I)] Percentage of variance accounted for of five participants versus different number of synergies](image1)

![Figure II) Synergies (a) and coefficients (b) of two runs of NMF; solid line (run 1), and dashed line (run 2). Eight muscles are Rectus Femoris (RF), Vastus Lateralis (VL), Vastus Medialis (VM), Biceps Femoris (BF), Semitendinosus (ST), Lateral Gastrocnemius (LG), Medial Gastrocnemius (MG), and Tensor Fasciae Latae (TFL).](image2)