SHARED SYNERGIES BETWEEN COMPLEX MOVEMENTS

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Introduction

Muscle synergy can be used to model how the central nervous system solves the redundancy problem of the musculoskeletal system [1]. It is assumed that each synergy vector W controls several muscles with a single activation command (= activation coefficient C). Previous studies found shared synergies across different movements, e.g., normal walking and: slipping [2]; standing reactive balance [3]; nordic-walking [4]. So far, no studies, evaluated if more complex movements also share the same synergies. This study aims to close this research gap, and therefore analyzes three different skateboard tricks, which are very complex, from a motor control perspective: Ollie, Kickflip (KF) and 360°-flip (Treflip). The twofold aim of the study was to (i) identify inter-subject variability and (ii) analyze number and behavior of shared synergies between tricks.

Methods

Surface electromyography (sEMG) data (Cometa, Milan, Italy) of 16 lower limp muscles (8 per leg) were collected of 7 healthy experienced skateboarders. Six successful trials per trick (Ollie, KF, Treflip, fig.1) were further analyzed. Raw sEMG data were band-pass filtered, demeaned, rectified, low-pass filtered, time-normalized for an interval between the lowest and highest point of a sacrum cluster marker (Vicon, Oxford, UK), concatenated and amplitude normalized. Muscle synergies were extracted by non-negative matrix factorization (NNMF) [5]. The individual number of needed synergies (NoS) was defined as the lowest number which fulfills our criterions for calculated total Variance accounted for (tVAF>90%, adding an additional synergy tVAF must not increase >1%). NoSoA was defined as the lowest number which fulfils the tVAF criterion for all conditions. Synergies were ordered across participants according to their cosine similarity (CS) of W [2]. Across participants, W was considered as similar if averaged Pearson's correlation coefficient r>0.623 [3], and/or CS>0.8 [4] for all possible pairs of participants. Additionally, C of each participant were reconstructed [4, 5] by W of all other participants and with random inputs W_{rand}. Reconstructed $tVAF_{rec}$ and $tVAF_{rand}$ was compared with original tVAF with repeated-measures ANOVA ($p<0.05$). Shared synergies between tricks (r>0.623) were determined per participant, firstly for NoSoA and further for NoS. Thus, r was calculated for all possible synergy pairs of W for two compared tricks. C_{rec} was calculated, with W of the other tricks and with W_{rand}. Then tVAF, $tVAF_{rec}$ and $tVAF_{rand}$ were compared as mentioned previously.

Results

NoS ranged from 4 to 5, 3 to 5 and 2 to 5 for Ollie, KF and Treflip, respectively. As a result, NoSoA was 5. Only the second synergy vector W of Ollie was similar ($r = 0.63\pm0.15$) across participants, consequently the inter-subject variability was rather high. For inter-subject variability the tVAF was significantly higher than $tVAF_{rec}$ and $tVAF_{rand}$. Also, $tVAF_{rec}$ was significantly higher than $tVAF_{rand}$. Number of shared synergies of NoSoA ($n_{sharedOA}$) was on the one hand different between participants per trick comparisons, and on the other hand different between comparisons for each participant (fig. 1). A similar result was obtained with NoS. In both methods it was notable, that at least one motor module was shared across all comparisons (Ollie = KF = Treflip). Reconstructions between tricks led to significantly higher tVAF values than $tVAF_{rec}$ and $tVAF_{rand}$. Again, $tVAF_{rec}$ was significantly higher than $tVAF_{rand}$.

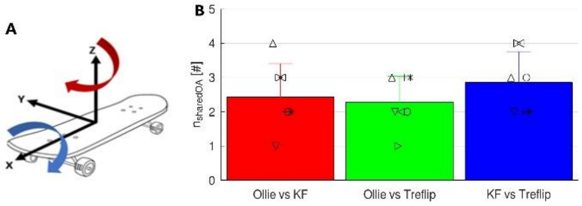

Figure 1 A: Tricks: Ollie= without any rotation; KF= with a 360° rotation around the x-axis; Treflip= with a 360° rotation around the x- and z-axis. B: $n_{sharedOA}$ for trick comparisons. Bars/errorbars = mean/standard deviation, markers indicate each participant.

Discussion

Unlike previous studies, which investigated inter-subject variability in complex movements [6], we found barely any similarity of W. As no previous studies had evaluated shared synergies among complex movements, our findings suggest, that at least one synergy is shared between different tricks, but the number of shared synergies does not follow certain rules between tricks and participants. Therefore, we conclude, that strategies to perform complex movements are very different across tricks and participants and require the development of trick-specific synergies. Moreover, the lower $tVAF_{rec}$, again points out the difference in motor modules between participants.

References

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