A PRACTICAL OPEN-SOURCE COMPARISON OF DISCRETE AND CONTINUOUS BIOMECHANICAL ANALYSIS TECHNIQUES

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Recent work has challenged the practice of extracting and analysing discrete summary metrics from continuous biomechanical data. This paper presents a practical comparison of candidate data analysis techniques including frequentist and Bayesian discrete analysis, frequentist and Bayesian statistical parametric mapping, and vector coding. Example 1 compares knee and hip flexion / extension angles during flywheel and barbell squats. Example 2 compares pelvis and thorax transverse rotations during badminton jump smashes by an international and a regional player. All example data and scripts are open-source. Statistical parametric mapping enables comparison of continuous biomechanical variables at time points other than discrete local optima. Combining this approach with vector coding provides information regarding differences in proximal-distal joint coordination throughout a movement. These continuous open-source methodologies can increase the validity and intuitive practical application of biomechanical conclusions.

KEYWORDS: Statistical parametric mapping, vector coding, flywheel, badminton.

INTRODUCTION:

"*One-dimensional biomechanical curves like ground reaction forces and kinematic trajectories are typically sampled at frequencies that can yield hundreds or thousands of values per recording… but hypothesis testing is usually conducted only on a relatively small number of summary metrics (e.g. values at local optima)*" (Pataky, 2012: 295).

Consider a practitioner wishing to make informed decisions between two training methodologies, or wishing to compare the technique of two athletes. How informative are maximum or minimum joint angles? What additional information may be of interest between these discrete time points? If our hypothesis relates to kinetic or kinematic time series then it is generally biased to test it using discrete parameters (Pataky et al., 2013, 2016).

This paper will compare the results and applications of discrete and continuous methodologies including: frequentist and Bayesian zero-dimensional discrete analysis; frequentist and Bayesian one-dimensional statistical parametric mapping (SPM); and vector coding. Each analysis will investigate two practical examples, representative of typical kinematic comparisons of means: 1) knee and hip flexion / extension angles during the flywheel squat and barbell back squat; and 2) pelvis and thorax transverse rotations during badminton jump smashes by an international and a regional player. All data and scripts with interactive examples are available at the Open Science Framework: doi.org/10.17605/OSF.IO/RAQZM

EXAMPLE ONE – FLYWHEEL AND BARBELL SQUATS:

Data: Eleven recreationally active males (22 ± 3 years; 1.79 ± 0.07 m; 79.1 ± 12.6 kg) performed 3 sets of 6 repetitions of both flywheel half squats and barbell half back squats for maximal concentric velocity. Flywheel inertia was 0.0291 kg·m^2 (D11 Sport, Desmotec, Biella, Italy) and barbell mass was that which matched flywheel concentric peak power during familiarisation. Retro-reflective markers were attached to each participant, and squats recorded using an 8 camera 3D motion capture system (300 Hz; 7+ series; Qualisys, Sweden). Knee and hip joint flexion / extension angles were calculated (Visual3D, C-Motion, Germantown, USA) for the middle four repetitions of each set. Eccentric and concentric phases were identified via hip joint centre vertical velocity. Mean time-normalised (eccentric: -100 – 0%; concentric: 0 – 100%) angle-time histories for each participant were used for all subsequent analyses (Figure 1).

Is there a difference in minimum joint angles between the two exercises?
A frequentist paired sample Student t-test (*i.e.* using p-values to compare minimum joint angles; α = 0.05; JASP Version 0.10) would suggest no difference in minimum knee angle between the flywheel and barbell squat (82.2 ± 7.4° *vs* 77.0 ± 6.3°; p = 0.104; Cohen's *d* = 0.540; 95% CI: -0.107, 1.164). Minimum hip angle was smaller (more flexed) in barbell compared to flywheel squats (108.2 ± 4.7° *vs* 118.0 ± 6.5°; *d* = 1.491; CI: 0.601, 2.349).

Advantages of Bayesian over frequentist (*i.e. p*-values) inferential statistics include the ability to provide probabilistic statements for both the null and alternative hypotheses, and to intuitively identify the most credible parameter values (see Kruschke & Liddell, 2018 for an introduction). Bayesian paired sample *t*-tests (prior: Cauchy, 0.707; JASP) show that for minimum knee angle the null and alternative hypotheses are almost equally likely (BF_{10} = 0.993), whilst for minimum hip angle a difference is 63.9 times more likely than the null (Figure 1). The relative likelihood of any given effect size can be plotted (Figure 2), including the 95% most credible values and the likelihood of an effect greater than any meaningful threshold. This distribution can be updated with each addition of new data or additional studies.

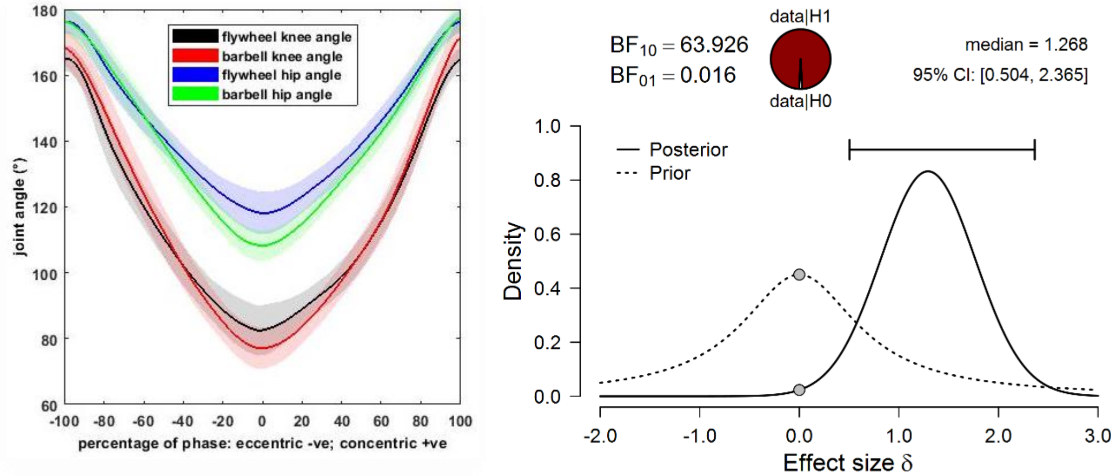

Figure 1: Left: Time-normalised knee and hip angles (± standard deviation). Right: Bayesian effect size distribution for minimum hip angle between flywheel and barbell squats.

Are there differences in knee or hip angles at other time points?
SPM uses random field theory to make comparisons across continuous time series (see Pataky, 2010 for an introduction). Frequentist (*i.e.* using p-values) SPM paired sample t-tests (open-source; spm1d.org; MATLAB v.2017b, The MathWorks Inc., Natick, MA) shone further light on the previously reported difference in minimum hip angles. Participants flexed their hips more in the barbell squat than the flywheel squat during the final 26% of the eccentric phase and the initial 38% of the concentric phase (Figure 2). There was no significant difference in knee angle at any time, although the more flexed knee at the end of the concentric phase in flywheel squats approached significance (p = 0.068). These inferences match those intuitively made from a visual analysis of normalised angle-time curves (Figure 1). In addition to these differences, Bayesian SPM (performed in R; open-source; Serrien et al., 2019) can indicate the strength of evidence for the null hypothesis (*i.e.* no difference between squat types). No such evidence was found at any time point in either joint angle.

Is there a difference in proximal (hip) or distal (knee) dominance at any time point?
Vector coding (vector between adjacent time points on an angle-angle plot) was used to assess proximal-distal joint coordination using the open-source MATLAB circular statistics toolbox of Berens (2009), and compared between conditions using SPM as previously described. Angles of 0° or 180° from the right horizontal indicated knee extension or flexion dominance (Figure 2). Angles of 90° or 270° from the right horizontal indicated hip extension or flexion dominance. On average, flywheel squats were more knee flexion dominant during the late eccentric phase,

more knee extension dominant during the early and late concentric phase, and more hip dominant during the mid-concentric phase compared to barbell squats (Figure 2). However, none of these differences reached evidence for the alternative or null hypotheses during SPM comparison.

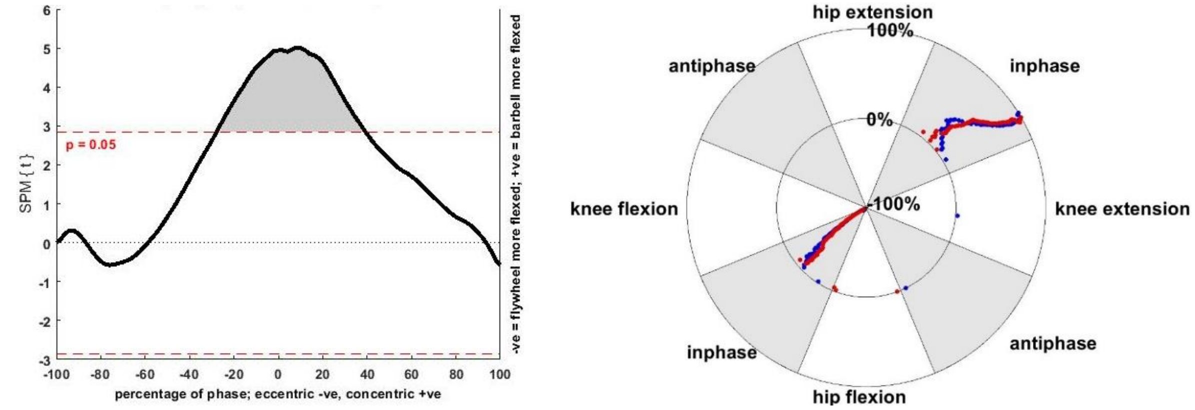

Figure 2: Left: Statistical parametric mapping comparison of time-normalised hip angles. Right: Proximal-distal joint coordination during flywheel (blue) and barbell (red) squats.

EXAMPLE TWO – BADMINTON JUMP SMASH:

Data: One international (19 years; 1.75 m; 78.3 kg) and one regional (22 years; 1.74 m; 71.4 kg) male badminton player performed twelve forehand jump smashes following match-representative lifts from an international player. Retro-reflective markers were attached to each participant, and smashes recorded using an 18 camera 3D motion capture system (400 Hz; M^2 MCam; Vicon, OMG Plc, Oxford, UK). Pelvis and thorax transverse plane rotations (0° = anatomical position; positive = racket side forwards; MATLAB) were calculated for the fastest six smashes by each participant. Time-normalised (0 - 100%; linear length normalisation) angle-time histories between preparation (lowest mass centre height) and shuttlecock contact were used for all subsequent analyses (Figure 3).

Is there a difference in maximum pelvis-thorax separation angle between the two players?
Maximum separation between the pelvis and thorax in the transverse plane (*i.e.* ‘X-factor’) has been positively associated with performance in sports such as golf, baseball, and cricket. In this example, a frequentist independent sample Mann-Whitney t-test indicated greater maximum separation in the international player compared to the regional player (40.1 ± 2.7° *vs* 26.7 ± 1.1°; p = 0.002; Hodges-Lehmann estimate = 12.5; CI: 10.8, 16.9). However, a Bayesian independent sample *t*-test showed that a difference is only 3.2 times more likely than the null hypothesis, and the 95% most credible effect sizes include zero effect (Figure 3).

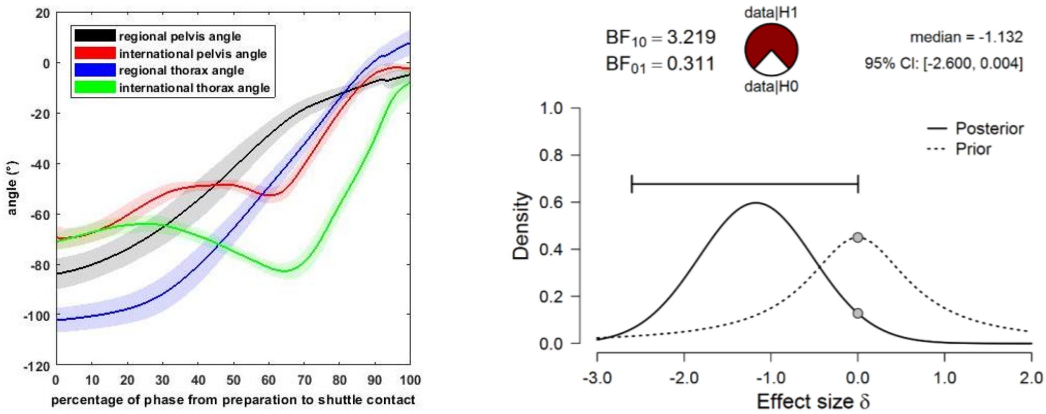

Figure 3: Left: Time-normalised pelvis and thorax angles (± standard deviation). Right: Bayesian effect size distribution for maximum pelvis-thorax separation in badminton jump smashes by an international and a regional player.

Are there differences in pelvis or thorax rotations at other time points?
Frequentist SPM independent sample t-tests revealed that the regional player initially had a more counter-rotated (racket side back) pelvis (0-34% of the smash) and thorax (0-41%) than the international player, but had a more forward rotated pelvis from 52 – 80% of the smash and finished with a more forward rotated pelvis (50 – 100%). Bayesian SPM revealed no evidence for the null hypothesis at any time point in either joint angle.

Is there a difference in proximal (pelvis) or distal (thorax) dominance at any time point?
Pelvis and thorax forward rotations were inphase throughout for the regional player except for a late thorax dominance (Figure 4). The international player's joint coordination was significantly (via application of SPM to the vector coding as described previously) more dominated by thorax counter-rotation from 32 – 61% and by pelvis forward rotation from 66 - 84% of the smash (Figure 4). No time point showed evidence for the null hypothesis. This distal (thorax) counter-rotation prior to proximal (pelvis) and then distal (thorax) forward rotation highlights both pelvis-thorax separation and proximal-to-distal sequencing by the international player. Such an analysis facilitates a more informative comparison than discrete time points or analysis of either segment in isolation.

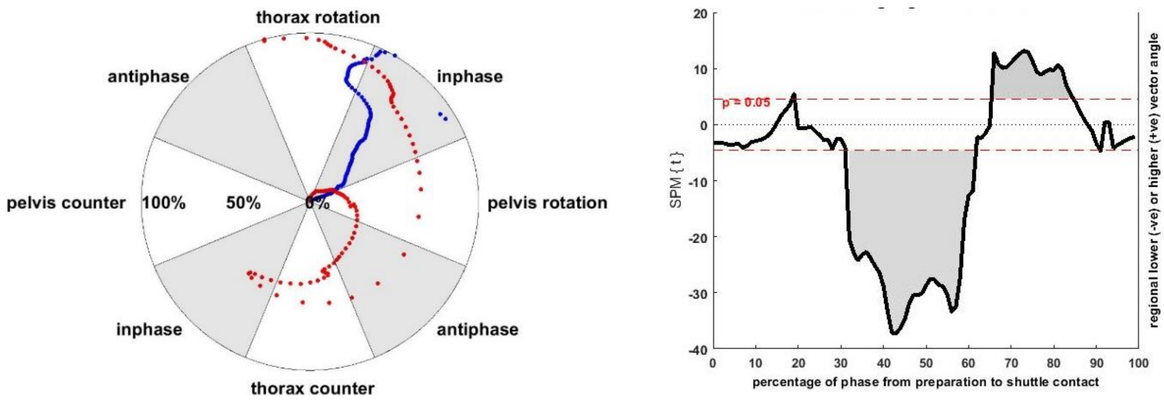

Figure 4: Left: Proximal-distal joint coordination in badminton jump smashes by an international (red) and a regional (blue) player. Right: Statistical parametric mapping comparison of proximal-distal joint coordination.

CONCLUSION:

Statistical parametric mapping enables comparison of continuous biomechanical variables at time points other than discrete local optima. Combining this approach with vector coding provides information regarding differences in proximal-distal joint coordination throughout a movement. These continuous open-source methodologies can increase the validity and intuitive practical application of biomechanical conclusions. Methodology selection should always be made with reference to the specific research question and hypothesis.

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