DETERMINATION OF THE OPTIMAL NUMBER OF RIGID-BODY SEGMENTS TO REPRESENT THE TRUNK USING AKAIKE'S INFORMATION CRITERION

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The purpose of this study was to determine the optimal number of rigid body segments to sufficiently represent the trunk movements, using Akaike's information criterion. The trunk in static and dynamic conditions was modelled with one, two, three, or six linked rigid-body representations. The difference in the three-dimensional position between the actual and modelled data was calculated to quantify how well these models describe the actual trunk kinematics. The Akaike's information criterion was calculated using the difference in position data to evaluate the goodness-of-fit for each model. Our findings suggest that two-linked rigid-body representation may be good enough when analysing trunk movements except when the movement includes a large axial rotation, for which the three-linked rigid-bodies would be better. These results would be useful in determining the optimal number of rigid body representation to sufficiently represent the trunk movements.

KEYWORDS: Modeling, Trunk deformation, Muitisegment, Likelihood, AIC

INTRODUCTION: In three-dimensional motion analyses, the trunk has often been simplified as a single or as a linkage of a small number of rigid-body segments to reduce the complexity of its multisegmental structure. When analysing the kinematics of the trunk during dynamic movements, the number of rigid-body segments to model the trunk significantly affects the resultant trunk kinematics (Kudo et al., 2018; Schinkely-Ivny et al., 2015). Since the degree of freedom (DOF) of the model increases as the number of rigid-bodies increases, it appears obvious that the errors on the trunk kinematics between the actual and modelled data should decrease. However, applying a larger number of rigid-body segments would not always be favourable, considering that the complexity of the analysis would also increase as the number of rigid-bodies increases.

The Akaike's information criterion (AIC: Akaike, 1974) would give a solution to the problem of selecting the best model to describe given data, when models may be constructed with a large number of parameters. AIC is a useful tool to determine the "best approximating" model among a class of competing models with different numbers of parameters. Therefore, the minimum number of rigid-body representation to sufficiently represent the trunk movements could be determined using AIC.

Therefore, the purpose of this study was to determine the optimal number of rigid body segments to sufficiently represent the trunk movements using AIC, when the trunk is modelled with a different number of rigid-body segments. In this study, the trunk in static and dynamic trials was modelled with one, two, three, or six linked rigid-body segments. The AIC value of each model was calculated to examine the goodness-of-fit of the model, and the model with the minimum value of AIC was selected as the optimal representation of the trunk.

METHODS: Ten male subjects participated in this study (mean ± SD age: 22.6 ± 1.5 years, 1.70 ± 0.05 m, 64.6 ± 6.0 kg). Three-dimensional kinematic data under static and dynamic movement conditions were obtained in this study. For the static trials, the subjects were asked to move the trunk to their limit of motion in each plane of motion (i.e., trunk lateral bending to the left and right sides, axial rotation to the left and right sides, thorax flexion, and thorax extension) and to keep their posture for 5 s. For the dynamic trial, the subjects were asked to walk barefoot along a 5 m walkway at a self-selected speed, as a representative motion commonly used in our life. A 24-camera motion capture system (MAC3D, Motion Analysis Corporation, California, USA) was used to capture the entire body motion. Three-dimensional position data were obtained at 250 Hz. Seventy reflective markers were placed on the back and front sides of the trunk at regular intervals (Figure 1). The markers were placed at the level of the seventh cervical vertebra (C7), third thoracic vertebra (T3), sixth thoracic vertebra (T6), ninth thoracic vertebra (T9), twelfth thoracic vertebra (T12), third lumber vertebra (L3), and first sacral vertebra (S1). Additional markers were placed at the posterior superior iliac spine and anterior superior iliac spine to define the pelvic reference frame.

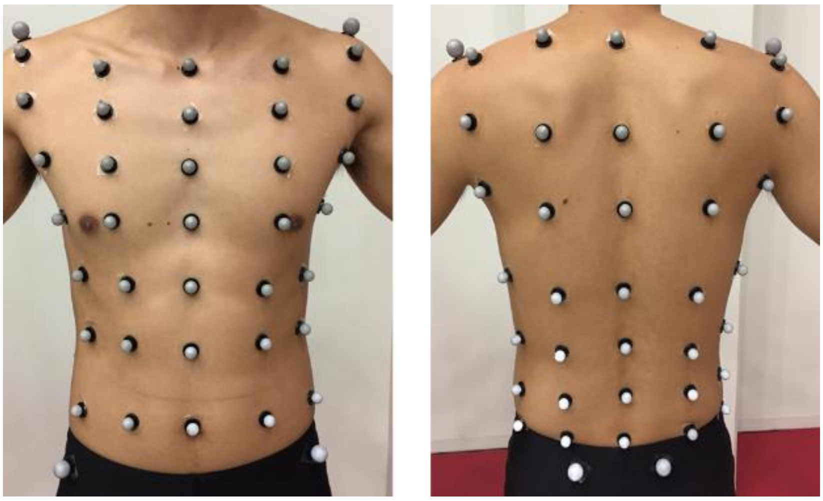

Figure 1: Marker placement

The trunk was modelled with one (M1), two (M2), three (M3), or six (M6) linked rigid-body segments (Figure 2). The local coordinate system was defined for each linked rigid-body segment and simultaneous transformation matrix (STM) from the local to global coordinate system was determined. Two adjacent segments of the trunk were linked with a ball joint, and thereby M1, M2, M3, and M6 individually had six, nine, twelve, and twenty-one degrees of freedom (DOF), respectively. The position error, i.e., the differences in the three-dimensional position between the actual and modelled position data, was calculated to quantify how well these models describe the actual trunk kinematics. A set of parameters for STM to minimize the position error was then found using an optimization algorithm.

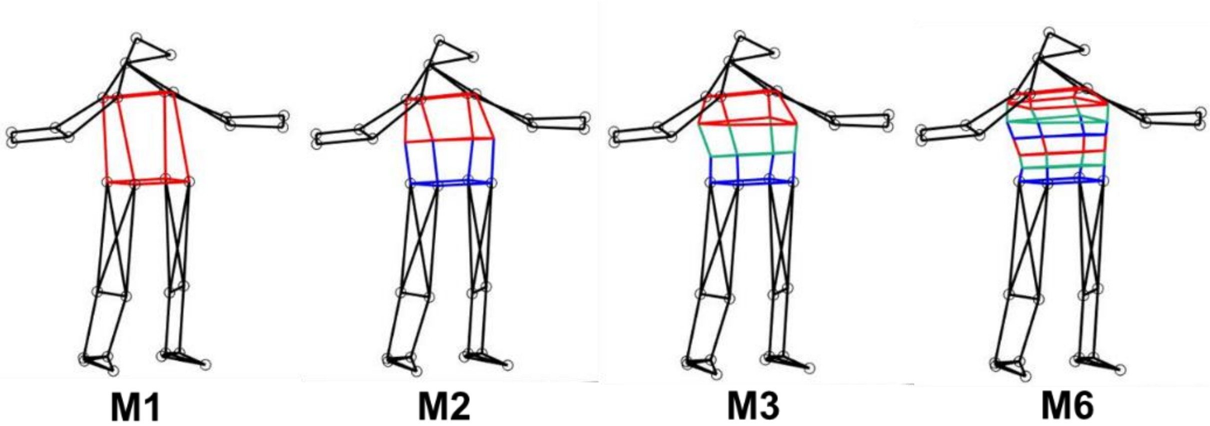

Figure 2: Linked rigid-body representations used in this study

AIC value of each model was calculated to examine the goodness-of-fit of the rigid-body representations as follows:

$$\mathrm{AIC} = -2 \times (\text{Logarithmic likelihood}) + 2 \times \mathrm{DOF} \quad (1)$$

where the DOF is the degree of freedom of each model. The model with the minimum value of AIC was selected as the optimal representation of the trunk.

A one-way repeated-measures ANOVA to investigate the main effect of the model (four models: M1, M2, M3, and M4) on the AIC value was performed using SPSS (Chicago, IL), and Bonferroni post-hoc analysis was performed for multiple comparisons between the model types when the ANOVA revealed a significant main effect. Significance level was set at $p < 0.05$.

RESULTS and DISCUSSION: A significant main effect of the model was found on the AIC values for all the postural conditions in the static trials ($p < 0.001$). The AIC value of M2 and M3 were significantly smaller than those of M1 and M6. Post-hoc multiple comparisons revealed that the AIC value of M3 was significantly smaller than that of the other models for the axial rotation condition. No significant differences between M2 and M3 in AIC value were found for the other postural conditions, except for the axial rotation. These results imply that the twisting movement of each segment appeared to be underestimated with a small number of segments, as it has been reported that each segment of the trunk significantly rotates during dynamic movement (Preuss et al.,2010). Therefore, these findings suggest that two-linked rigid-body representation may be good enough when analysing the trunk movements except when the movement includes a large axial rotation, for which the three-linked rigid-bodies would be better.

For the dynamic condition, a significant main effect of the model was also found on the AIC value ($p < 0.001$). The AIC values of M2 and M3 were significantly smaller than those of M1 and M6.(Figure 3-e). Post-hoc multiple comparison demonstrated no significant difference in the AIC values between M2 and M3. These results indicate that the two or three linked rigid-body representations would be better than one or six linked rigid-body representations to analyse the trunk movement during walking. Considering that the AIC value was comparable between the M2 and M3 models, two-linked rigid-body representation would be good enough to represent the trunk movement during walking.

CONCLUSION: We quantitatively assessed the goodness-of-fit of the model when the trunk was modelled with a different number of rigid-body segments using the AIC value. Our findings suggest that two-linked rigid-body representation may be good enough when analysing trunk movements except when the movement includes a large axial rotation, for which the three-linked rigid-bodies would be better. These results would be useful in determining the optimal number of rigid body representation to sufficiently represent the trunk movements.

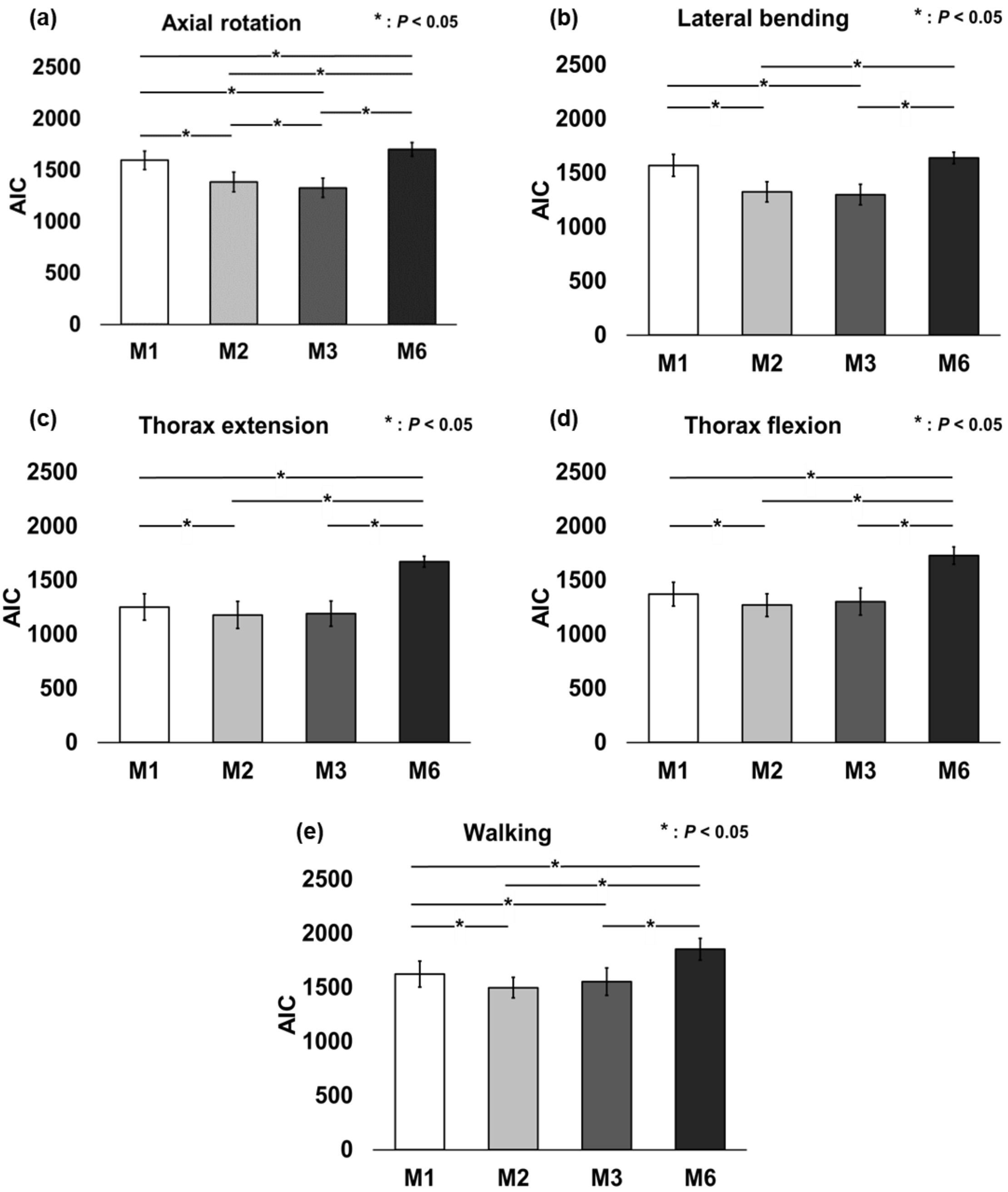

Figure 3: AIC values in static (a) axial rotation, (b) lateral bending, (c) thorax extension, (d) thorax flexion), and dynamic conditions (e) walking

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