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QUANTIFICATION OF NET POWER OUTPUT DURING EXERGAMING USING A SINGLE-MASS, MULTI-SEGMENTAL KINETICS AND JOINT POWER MODEL: A COMPARISON WITH INDIRECT CALORIMETRY

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SUMMARY

Background: Exergaming could be an effective strategy to increase physical activity energy expenditure (EE). An effective exergame should reward EE during gameplay yet the prediction of EE using current metabolic techniques is not practical outside of laboratory conditions. As alternatives, three classical biomechanical approaches to the problem of quantifying net power output (NPO) are proposed. These are based on a single-mass model, a multi-segmental kinetic model and a joint-power model. The aim of this study is to quantify the relationship between NPO using the three models and the rate of EE during gameplay. **Methods:** Kinematic, inertial and metabolic data were collected from 15 adults whilst playing a purpose-built boxing-based exergame. The participants were required to punch against resistance bands using a ramped test protocol. A mixed linear regression model was used to quantify the relationship between NPO and EE. **Results:** Regression slopes of NPO against EE were 13.26 (CI =8.43 to 18.0), 8.73 (5.64 to 11.82) and 4.74 (4.18 to 5.30) for the single-mass model, segmental-kinetics model and joint-power model, respectively. Typical errors of measurement were 1692, 1577 and 1010J/min. **Discussion and Conclusion:** While it is recognized that there are limitations inherent in the biomechanical models and also in the criterion method chosen, the results are nonetheless positive and highlight the potential use of biomechanical modeling to the energetics of exergaming. Of the models tested, the output from the joint-power model had the strongest relationship with EE.

INTRODUCTION

Exergaming, or active gaming, is a fairly new phenomenon which was first popularized by Nintendo and adopted more recently by Sony and Microsoft. Although screen time and in particular video game use has been associated with an increased risk of metabolic syndrome and obesity (3), exergames may be an opportunity to increase physical activity in adults and children (2, 8). A potential feature of an effective exergame is that it can reward true EE during gameplay. However, assessment of EE outside of the lab is problematic. In contrast, net power output (NPO) which is correlated with the rate of EE, can be modeled using kinematic data. Advances in manufacturing techniques have led to the increased availability of low-cost motion capturing systems and it is expected that these technologies will offer new opportunities for the application of biomechanics-based energetic models during exergaming. The aim of this study is to quantify the relationship between NPO and EE from three classical biomechanics-based models of energetics.

METHODS

Data Collection: Healthy individuals (11 males and 2 females; age 29±5 years, height 179.2±9.2cm; weight 76.2kg±9.5kg) were recruited for this validation study. Ethical approval (Teesside University Ethics committee) and informed consent were obtained. Reflective markers (14mm) were placed on the spinous process (C7), SC and AC joints, deltoid tuberosities, lateral epicondyles and styloid processes. Hand-pieces (ShadowBoxer Pty, Australia) were held in an anatomical power grip. The hand-piece was connected via a resistance band to a belt around the thorax. Markers were also placed on the hand-pieces and on the belt (at the anatomical midline and 10cm laterally). The motion data was captured using a six camera motion capture system (Vicon, UK) at 100Hz. The data were supplemented with orientation data from five IMUs (inertial measurement units). Their locations were the deltoid tuberosities, hand-pieces and belt. Orientation quaternions were calculated by the gradient descent algorithm with a correction weighting of 0.1 (7) and an internal sampling rate of 200Hz. The data was input to a kinematic model which included segmental representations of the trunk, head-neck, upper arms and lower arms. Hands/lower arm and the head/neck were modeled as single segments. Indirect calorimetry was simultaneously recorded using a portable metabolic system (Cosmed K4b2, Rome, Italy). A 7-breath average was applied to calculate a net rate of metabolic EE (6).

Net Power Output: The NPO models were based on a single-mass model (4), multi-segmental mass model (9) and multi-joint model (1). Input for the single-mass model was the acceleration magnitude from the IMU positioned on the belt (i.e. close to the COM). Input for the multi-segmental kinetics and joint-power models were from a kinetic model derived using inverse dynamics (5).

Protocol and Data Analysis: The exercises representing exergame moves were based on shadow-boxing. The exercise routine was controlled by a game display providing visual and audio prompts at regular intervals

(Figure 1a). At the instant at which these prompts hit a stationary bar (J = Jab, H = Hook and U = Upper-cut) participants are required throw the relevant punch. A ramped test protocol was developed in which the punching rate started at 70 punches per minute (ppm) for the first minute and then increased incrementally by 10ppm every minute for ten minutes, up until the point of volitional exhaustion or when NPO dropped below a threshold level (2000J/Min). Increases in prescribed punch frequency were accompanied by an instantaneous increase in NPO but not in EE. To allow for differing responses, the NPO data were smoothed using a moving average window of -30s. The relationship between the smoothed NPOs and rate of EE was quantified using a mixed linear regression model with an unstructured covariance matrix. Within-subject regression equations and typical errors of prediction are reported.

RESULTS

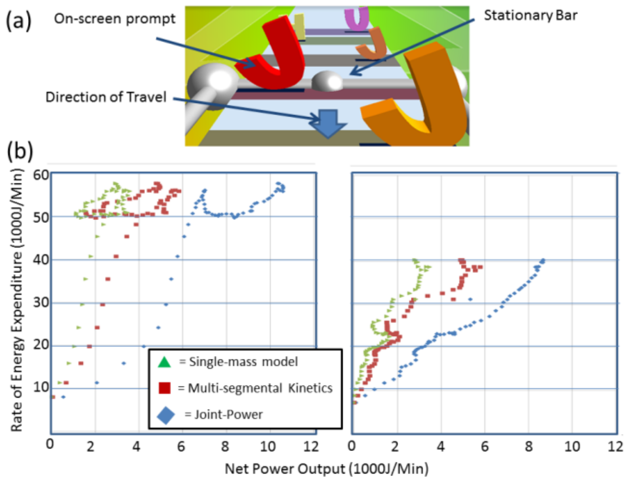

Figure 1. a) The game interface showing the "Left JAB" punch crossing the stationary bar. The prompts on the left are for the user’s left hand and on the right are for the user’s right hand. b) NPO versus physiological EE for two individuals. On the left is example data from an individual who over-exerted early on and on the right is a more typical example from an individual who maintained steady-state aerobic exercise for longer.

From the outset some individuals underwent a rapid rise in terms of physiological EE (Figure 1b left) whereas the majority of the individuals underwent a more gradual increase (Figure 1b right). The slopes of the regression curves (Table 1) were lowest for the joint-power model, and highest for the single-mass model. The confidence intervals and the typical errors of prediction were substantially lower for the joint-power model than the other models.

DISCUSSION

In addition to the known limitations of biomechanical energetics, there were several limitations specific to this study. Notably, whilst throwing a punch some individuals used their lower body much more than others. These movements were not included in the models, thus leading to a probable underestimate of NPO. In addition, their effort levels tended to rise more steeply and reached anaerobic levels much sooner than those of the other individuals. Since anaerobic EE cannot be measured with indirect calorimetry (Figure 1b left), it is probable that measured EE was an underestimate of the true metabolic cost. Coincidentally, these underestimates of NPO and EE affected the same individuals and thus to some degree cancelled each other out. Thus, somewhat fortuitously, the regression slopes were relatively unaffected by these underestimates and remained fairly consistent despite these known limitations.

The joint-power model is the most feasible for predicting EE from calculated NPO. The regression slopes for the joint-power model were quite stable and the typical errors (1010J/min) are considered acceptable. Although the models are not yet ready to be applied to the general population, they do provide a reasonable predictive too for tracking an individual’s EE when performing typical exergame moves.

CONCLUSIONS

NPO is a viable method of predicting EE on an individual level whilst exergaming and it was found that the joint-power method performed the best.

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Table 1. Regression slopes and typical errors of three biomechanics models. (CI = confidence interval).

Biomechanical model	**Regression slopes**	**Typical errors (J/min)**
Single-mass model	13.26 (CI =8.43 to 18.0)	1692
Segmental-kinetics	8.73 (CI = 5.64 to 11.82)	1577
Joint-power model	4.74 (CI =4.18 to 5.30)	1010