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Kinetics of hula hooping: An inverse dynamics analysis

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Available online 10 April 2008

Abstract

This paper involved a biomechanical analysis of lower limb joint coordination during hula hooping. A lower extremity inverse dynamics model that incorporated kinematic input and force platform data was developed to compute the angular velocities, moments about and powers produced at the lower extremity joints. The abductor moments and powers were discovered to be paramount in maintaining hoop oscillations, as demonstrated consistently in the three study participants. However, hula hooping was demonstrated to be variable in terms of the involvement of flexor and extensor moments and powers of the ankle, knee and hip joints, resulting in the adoption of varying strategies by each of the three participants.
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1. Introduction

Little scientific attention has been paid to the complex task of hula hooping. In fact, the only systematic research to date was the descriptive kinematic analysis offered by Balasubramaniam and Turvey (2004). These authors applied dynamical systems theory to demonstrate that only two coordinative modes were sufficient to maintain the hoop's oscillations. The current paper examines hula hoop performances by applying inverse

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dynamics to yield additional information concerning what moments of forces of the lower extremity are necessary to sustain motion of the hula hoop.

Hula hooping is a complex task, the functional goal being to keep a hoop in continuous oscillation parallel to the ground via coordinated body movements (Balasubramaniam & Turvey, 2004). The physical basis of hula hooping is the generation and conservation of angular momentum. In short, the performer must exert regulated impulses to create a state of dynamic hoop equilibrium. Two requisite conditions need be satisfied to sustain the equilibrium state. First, a vertical component of the exerted impulse necessarily opposes the force of gravity and secondly, a simultaneous horizontal component maintains the angular motion of the hoop (Balasubramaniam & Turvey, 2004).

The work of Balasubramaniam and Turvey (2004) performed a decompositional analysis of hula hooping kinematics, using a Karhunen–Loève (K–L) transform, to outline the coordinative modes of limb motion which best describe hula hooping. Succinctly, the K–L transform was used to compute orthogonal eigenvectors that characterized the spatiotemporal patterning of the lower limb joints involved in hula hooping. The more prominent motions that characterized hula hooping explained greater variance (for a detailed explanation of principal component analysis in human movement analysis see Daffertshofer, Lamoth, Meijer, & Beek, 2004). The K–L technique revealed dynamic equilibrium was sustained through concurrent oscillatory motions of the hips, knees and ankles, thereby satisfying the characteristic functional constraints of the task. The analysis revealed two principle processes operated to sustain oscillatory motion, the most prominent of which was the fore-aft motion of the hips that sustained the hoop's angular motion. Of secondary importance was the mechanism controlled at the knee, which created a vertical component to oppose the force of gravity (Balasubramaniam & Turvey, 2004).

The formation of movement trajectories that characterize hula hooping is extremely complex. This complexity is exacerbated because the relation between joint trajectories and the position of end effectors is ambiguous (Feldman, 1986; Lacquaniti & Soechting, 1982; Polit & Bizzi, 1978). Researchers refer to this phenomenon as the equivocality principle (Bardy, Marin, Stoffregen, & Bootsma, 1999; Turvey, Fitch, & Tuller, 1982) which implies that the control of motion cannot be based directly on kinetic, neural, or sensory information (Bardy et al., 1999). Whereas the dynamical systems approach was concerned with describing the abstract kinematic patterning of the limbs in maintaining hoop oscillations, it did not describe how these movement patterns were produced. Therefore, at present little is known about individual joint contributions to the overall coordinative modes or patterns of motion that characterize hula hooping, leaving ambiguity and room for interpretation. Given the equivocal relationship between joint trajectories and the movement of end effectors, the physical complexity of hula hooping and the linked nature of the lower limbs, it is hypothesized that individual joint contributions to the overall kinematic patterning of the lower limbs will vary in maintaining hoop stability. The hypothesis will be tested using an inverse dynamics analysis, which computes the joint moments and moment powers underlying motion. Thus, the objective of the present research was to reveal the kinetic equivalent of existing dynamical systems research to determine whether the approaches yield complementary conclusions, thereby culminating in a more comprehensive understanding of hula hooping. In short, we sought to determine whether inverse dynamics could further our understanding of hula hooping by revealing the contribution of the individual joint moments to the maintenance of dynamic equilibrium.

2. Methods

Three females voluntarily participated in this experiment. All participants were intermediate-level hula hoopers selected based on the criterion that they could comfortably (in terms of speed, smoothness, and stability) sustain hoop oscillations for a period of 20 s. None of the participants had previous competitive experience. The age range was 16–23 years, with a mean of 19.3 years. Their heights ranged from 164–168 cm, with a mean of 165.3 cm. Prior to engaging in the experiment, the participants provided written consent. The hula hoop (Wham-O Corporation, Torrence, CA) was 70.4 cm in diameter and weighed approximately 184 g.

The participants were required to hula hoop at their self-selected pace for 20 s. The data collection process began when the participant expressed comfort with hoop oscillations in terms of speed, smoothness, and stability. Five 20 s trials were collected per participant. The experimental condition used in this research was reflective of that used by Balasubramaniam and Turvey (2004) so that we could examine individual joint contributions to the hula hooping task.

Movements were recorded using a five-camera Vicon (Lake Forest, CA, USA) motion analysis system. Fourteen-millimetre reflective spherical markers were positioned bilaterally on the participants' limbs at the hallux (TOE), 1st and 5th metatarsophalangeal joints (MT1 and MT5), calcaneus (CAL), medial and lateral malleoli (MAN, LAN), shank (TIB), medial and lateral femoral condyles (KNE, MKN), thigh (THI), greater trochanter (HIP), and the anterior (ASI) and posterior superior iliac spines (PSI), according to the uOttawa marker set represented in Fig. 1. Briefly, the uOttawa marker set was derived from the Vicon Plug-in-Gait marker set but was modified by incorporating hip markers and medial ankle and knee markers. This marker set permits six degrees of freedom and the requisite three independent, non-collinear surface markers necessary to track motion in 3-dimensional space (Winter, 2004). Furthermore, the uOttawa marker set places markers at well-defined bony landmarks of the lower limbs. This practice increases both the within- and between-day reproducibility of joint kinematics and kinetics during locomotion (Yu, Queen, & Schrodt, 2003). The sampling frequency for motion capture was 200 Hz. Synchronous force platform data were also sampled at 200 Hz from two adjacent multi-component force platforms (9286A, 9281C; Kistler Instrumente AG, Winterthur, Switzerland).

At the outset of each trial the participants were instructed to step off the platform for zeroing to reduce sensor drift during prolonged stationary periods. Motion and analog ground reaction force data were recorded using Vicon Workstation and then exported to and analyzed with Visual3D, version 3.79. The digitized marker coordinates were filtered with a fourth-order Butterworth low-pass digital filter (cf. Pezzack, Norman, & Winter, 1977; Robertson & Dowling, 2003; Winter, Sidwall, & Hobson, 1974) with 4 Hz cut-off frequencies, due to the low frequency content of the data.

The analog force platform signals were filtered with a fourth-order Butterworth low-pass digital filter with a cut-off frequency of 10 Hz. The joint and segment kinematics and force platform signals were incorporated into a standard link segment model (Bresler & Frankel, 1950) to compute joint angular velocities (rad/s) and body mass normalized, moments of force (N m/kg) and moment powers (W/kg) at the ankles, knees, and hips of both lower extremities.

Joint angular velocities, moments, and power were projected onto local coordinate systems embedded at the proximal joint centers of the distal segments that form the joints.
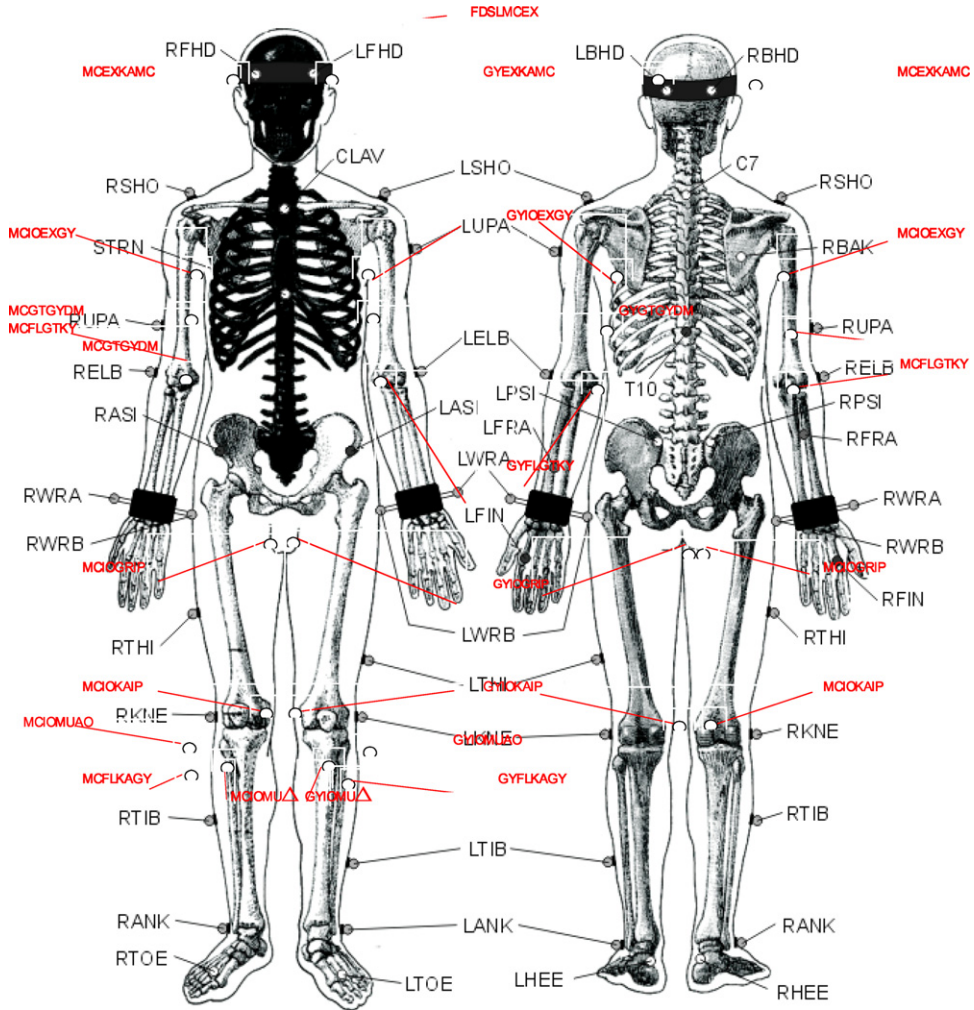
Fig. 1. Schematic representing placement of reflective markers according to the uOttawa marker set, which has been derived from the Vicon Plug-in-Gait (PiG) placement. Small white circles represent PiG marker placements; large dark circles represent the modified uOttawa marker placements. *Only lower limb markers were required for this study, to the level of the pelvis.

These local coordinate systems use a z-axis (axial rotation) that projects from the proximal joint center to the distal joint center of each segment. The y-axis (ab/adduction) is formed by projecting an axis orthogonal to the plane formed by at least three (medial and lateral) markers that define the proximal and distal joint centers (e.g., for the shank this plane is defined by the medial and lateral condylar and malleoli markers). The x-axis (flexion/ extension) is the cross-product of the z and y axes producing a right-handed orthogonal axis system. For example, ankle moments and powers are projected onto the foot's local coordinate system located at the ankle. Note that abductor angular velocities and moments of the left side are defined as positive, whereas, the right side abductor moments and velocities are reported as negative values. For flexion and extension, the sign conven-

tion is as follows: ankle plantiflexion (extension) is negative, ankle dorsiflexion (flexion) positive; knee extension is defined as positive, knee flexion as negative; while at the hip, flexion is considered positive whereas extension is negative.

3. Results

Figs. 3–7 show the ensemble averaged angular velocities (top rows), moments of force (middle rows) and their powers (bottom rows) of left (dashed lines) and right (solid lines) ankles (left columns), knees (middle column) and hips (right columns). The moments and powers are normalized to body mass for inter-subject comparisons and all axes are scaled similarly within a figure. Note that the ordinate scaling for Figs. 3 and 4 (ab/adduction) are different from the scaling for Figs. 5–8 (flexion/extension). The temporal axes (abscissas) are scaled to percentages of three cycles. Each 20 s trial was divided into five series of three cycles (for a total of 75 cycles). Ensemble averages and standard deviation of the 25 series were computed for each participant. Only Fig. 8 shows standard deviations of the various dimensions. Series divisions were based on the trajectories of the right anterior superior iliac spine (RASI, Fig. 1). Notice that the variability between cycles and across 3-cycle series was small.

Fig. 3 is an exemplar taken from participant 1 that illustrates the abduction/adduction angular velocities, moments, and powers observed for the various joints. Note that due to the orientation of the joint axes depicted in Fig. 2, abductor angular velocities and moments of the left side are defined as positive. However, the right side abductor moments and velocities are considered negative.

Fig. 3 demonstrates that little abduction or adduction was performed about the ankle joint, as evidenced by small normalized moments that produced insignificant powers. The knee joint exhibited fluctuations of abductor and adductor moments that produced approximately equal amounts of positive and negative work. There were, however, substantial asynchronous abductor moments observed about the hip for both the left and right legs. The abductor moments produced large bursts of positive and negative work making the abductor moment the prime mover during hula hooping. All three participants showed similar bursts of power and moments of forces about the abduction/adduction axes at the ankle and knee joints. Fig. 4 illustrates the abduction/adduction angular velocities, moments and powers observed about the hip joints of all three participants. The sign convention for Fig. 4 is the same as Fig. 3. All three participants adopted similar strategies, as demonstrated by similar angular velocities, moments, and power histories.

Figs. 5–7 show the flexion/extension angular velocities (top row), moments (middle row), and moment powers (bottom) observed for the right and left ankles (left column), knees (middle column) and hips (right column) for Participant 1, 2 and 3, respectively. The sign convention follows the right-hand rule therefore; ankle plantiflexion (extension) is considered negative, ankle dorsiflexion (flexion) positive. For the knees, extension is defined as positive, flexion as negative, while at the hip, flexion is considered positive whereas extension is considered negative.

Fig. 5 shows the flexor/extensor joint kinematics and kinetics for Participant 1. This subject exhibited little plantiflexor or hip extensor power to maintain the hoop oscillations, even though substantial plantiflexor moments were evidenced (peaks at approximately -0.6 N m/kg). Conversely, there were relatively larger angular velocities at the hips but relatively low moments of force producing small amounts of work and power. At the
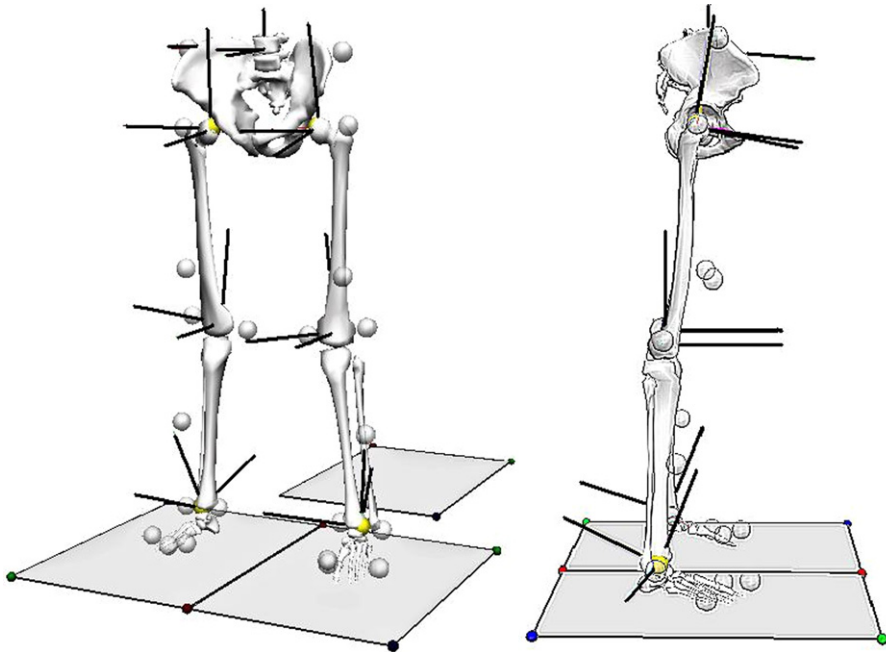
Fig. 2. An orthogonal joint axis system was employed to compute segmental kinematics, moments, and moment powers for the present research. Joint angular velocities, moments, and power were projected onto orthogonal local coordinate systems embedded at the proximal joint centers of the distal segments that form the joints. These local coordinate systems use a *z*-axis (axial rotation) that projects from the proximal joint center to the distal joint center of each segment. The *y*-axis (ab/adduction) is formed by projecting an axis orthogonal to the plane formed by at least three (medial and lateral) markers that define the proximal and distal joint centers (e.g., for the shank this plane is defined by the medial and lateral condylar and malleoli markers). The *x*-axis (flexion/extension) is the cross-product of the *z* and *y* axes producing a right-handed orthogonal axis system.

knees, there were alternating extensor bursts of eccentric (right side) and concentric (left side) work and power.

Fig. 6 shows the flexor/extensor joint kinematics and kinetics for Participant 2. This participant produced different kinetics patterns than Participant 1 in that significant powers were developed by the left ankle plantiflexors by relatively larger plantiflexor moments. Conversely, the right ankle plantiflexors produced almost no work and relatively minor levels of plantiflexor moments of force. Other major differences were the smaller bursts of power from the knee extensors and the larger bursts from the hip flexors and extensors alternating between concentric and eccentric work, performing net positive work by the right hip moment and both positive and negative work by the left hip moments.

Fig. 7 shows the flexor/extensor joint kinematics and kinetics for Participant 3. Again this participant produced different kinetics than either Participants 1 and 2. Her plantiflexor powers were asymmetric with the left side performing positive work while the right side did negative work but half a cycle later. The knee moments were also different alternating between extensor moments of the left leg doing positive work but the right extensor doing predominantly negative work but one half cycle out of phase. At the hips, the moments alternated between flexor and extensor phases. In contrast with the ankle and
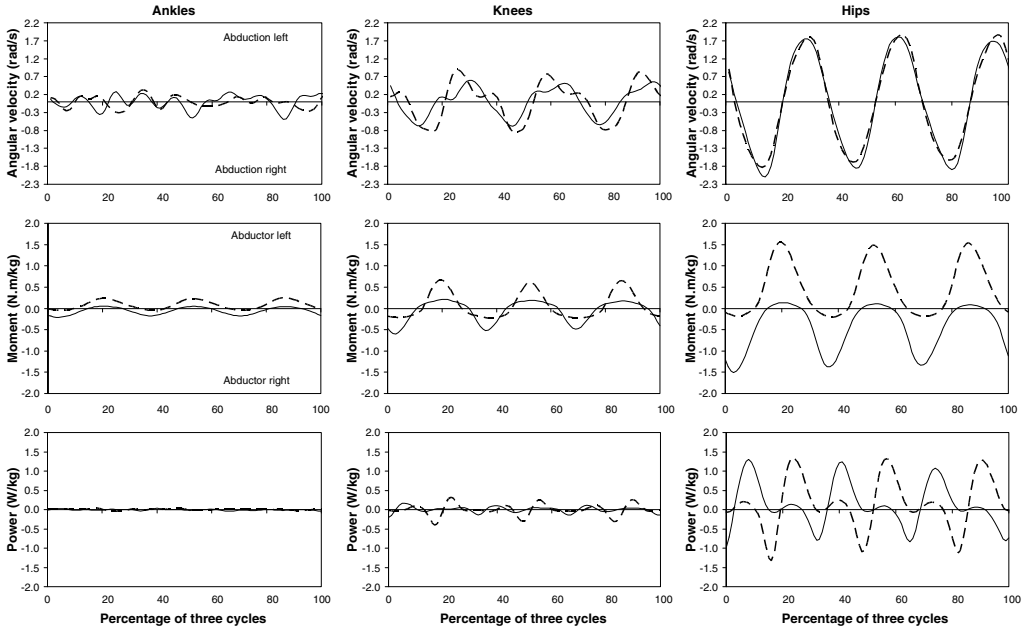
Fig. 3. Abduction/adduction angular velocities (top row), moments (middle row), and powers (bottom row) of the ankles (left column), knees (middle column), and hips (right column) during hula hooping (Participant 1). Left side represented by bolded dashed line, right side by thin solid line. Abductor angular velocities and moments of the left side are defined as positive; right side moments and velocities are negative.

knee moments, the hip moment powers were in phase and both alternated between bursts of positive and negative work.

Fig. 8 presents data from Subject 1 on the flexion–extension moments and powers for the right and left ankle, knee and hip joints during hula hooping. Error bars are included to demonstrate the within-subject variability.

4. Discussion

The results demonstrated that while the hip ab/adduction involvement was similar across participants, the contribution from the ankle, knee, and hip flexors/extensors varied across participants. In fact, where one participant used a "knee" strategy, the others used an "ankle-hip" strategy, or a balanced strategy that incorporated the ankle, knee, and hip flexors/extensors.

As demonstrated in Fig. 3, there was substantial work done by the hip joint projected onto the ab/adduction axis. For the participant illustrated, the right moment did positive work at the onset of the motion, signifying that the hoop was spun in a clockwise direction (toward the left hip). As such, the moment of force patterns observed in Fig. 3 exhibited repetitive hip abductor moments followed by a brief adductor burst while the contralateral side responded with opposing moments. In other words, the left and right side moments demonstrated an anti-phase or 180° out-of-phase recruitment pattern with respect to each other. These results concur with those reported by Balasubramaniam and Turvey (2004),
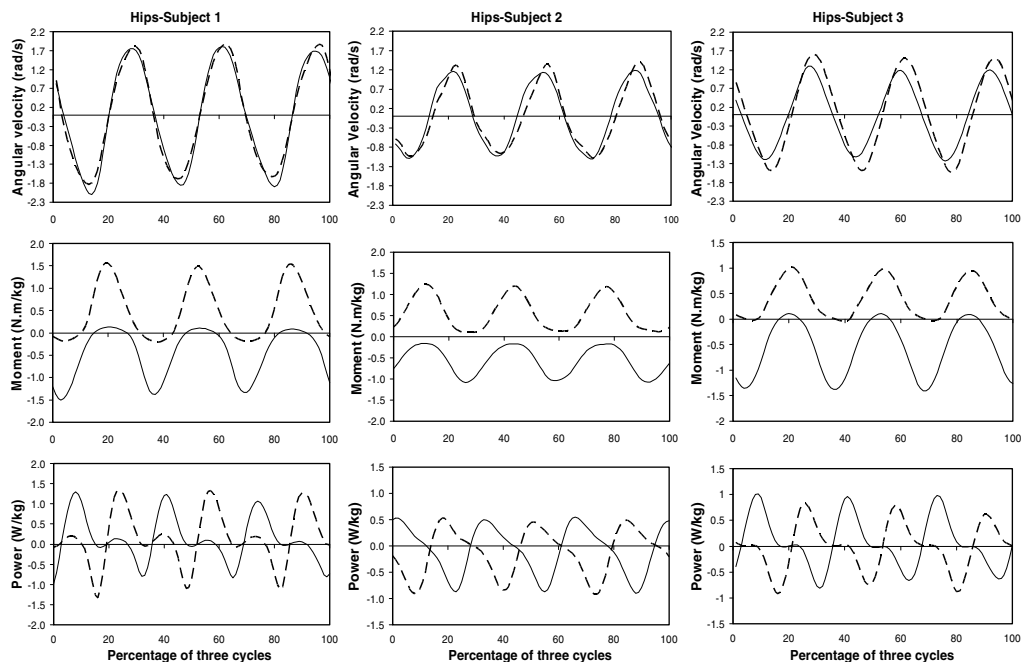
Fig. 4. Abduction/adduction angular velocities (top row), moments (middle row), and powers (bottom row) of the hip joints during hula hooping (Participants 1, 2, and 3). Left side represented by bolded dashed line, right side by thin solid line. Abductor angular velocities and moments of the left side are defined positive; right side abductor moments and velocities are negative.

where the side-to-side motion of the hip, which represented the first eigenvector or coordinative mode generated by the decompositional analysis accounted for the most variance and thus, was concluded to be the prominent motion in the hula hooping task. Balasubramaniam and Turvey (2004) refer to this eigenvector as a fore-aft motion but it is equally possible to call it a side-to-side motion because the hoop oscillates in all directions in the horizontal plane throughout a cycle. It now appears more suitable to call it a side-to-side motion since the causes of this eigenvector are the actions of the hip abductor moment and to a lesser extent the adductor moment.

Fig. 3 also demonstrates that while there were abductor/adductor moments about the knee and ankle joints, these performed little work in comparison with the hip moments of force. This finding comes as no surprise since there are few and weak muscles spanning these joints capable of producing significant amounts of work. The angular velocity curves depicted in Fig. 3 suggest that while there was frontal plane motion at the level of the knee, little work was performed by the knee abductor–adductor moments. The observed knee abductor–adductor moments most likely contributed to support during the maintenance of upright stance. Conversely, the frontal plane knee moments may be accounted for by ligamentous forces that create or resist abduction/adduction about these joints. On the other hand, there are muscles spanning the ankle joint capable of producing significant frontal plane moments. However, as demonstrated in Fig. 3, the frontal plane moments were quite small. Further, when coupled with the small frontal plane angular velocities,
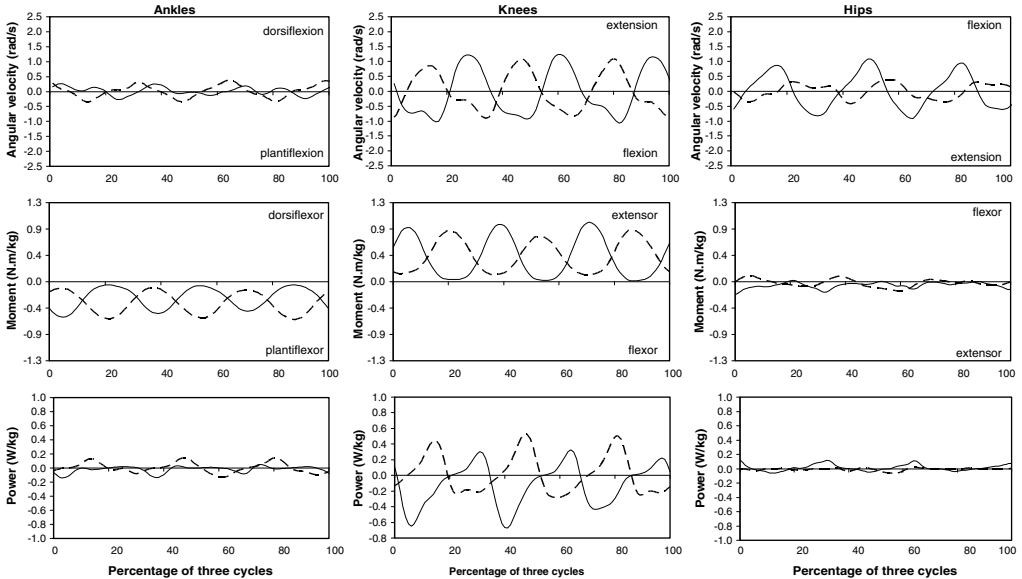
Fig. 5. Flexion/extension angular velocities (top row), moments (middle row), and powers (bottom row) of the ankles (left column), knees (middle column), and hips (right column) during hula hooping (Participant 1). Left side represented by bolded dashed line, right side by thin solid line. Ankle plantiflexion moments and angular velocities (extension) negative, ankle dorsiflexion (flexion) positive. For the knee joints, extensor moments and velocities are positive, flexor negative; at the hip, flexor moments and velocities are positive, extensor moments and velocities is negative.

the resulting powers in the frontal plane rotational axis were small. As a result, very little mechanical work was performed by the ab/adductor moments about the ankle joint. A limitation of this work is that muscle activation was not of primary concern and thus, was not directly measured, rendering the analysis speculative for the present. However, despite the inability to unambiguously partition the knee and ankle abductor–adductor moments to muscle and/or ligament sources, the involvement of these moments seems to be of tertiary importance in contributing to hoop oscillation.

Fig. 5 shows Participant 1's angular velocities, moments, and powers during flexion/ extension of the ankle, hip and knee while hula hooping. This participant performed little work at the ankle and hip to sustain the hoop oscillations; instead she relied almost exclusively on the extensor moments of the knee. As previously argued by Balasubramaniam and Turvey (2004), the data collected for Participant 1 suggest that the knee extensor moment was paramount in providing the vertical impulse necessary to prevent the hoop from descending gradually to the ground. Further, Fig. 5 shows that in the case of Participant 1, net positive work was done by the extensor moments of the left knee and negative work by those of the right knee. Since the hoop itself is of relatively insignificant mass (184 g), the work performed by the knee extensor moment must have been related to raising and lowering the body's center of mass (COM). As the hoop was oscillating about the hips, the change in height of the COM would serve to simultaneously contribute to the vertical component of the impulse directed into the hoop. These moments performed work in an asymmetrical pattern, that is, the data suggest that net positive work was done while
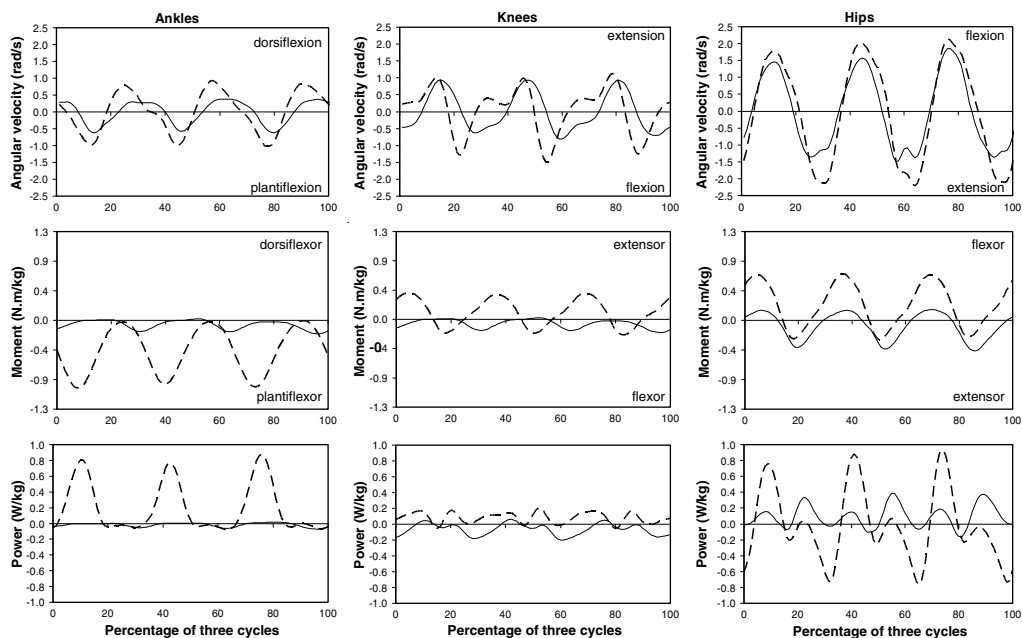
Fig. 6. Flexion/extension angular velocities (top row), moments (middle row), and powers (bottom row) of the ankles (left column), knees (middle column) and hips (right column) during hula hooping (Participant 2). Left side represented by bolded dashed line, right side by thin solid line. Ankle plantiflexion moments and angular velocities (extension) are negative, ankle dorsiflexion (flexion) positive. For the knee joints, extensor moments and velocities are positive, flexor negative; at the hip, flexor moments and velocities are positive, extensor moments and velocities negative.

the participant stood on the left leg and conversely, net negative work was done while the participant stood on the right leg. These results signify that the extensor moment at the left knee worked concentrically to raise the body, whereas eccentric work performed by the left knee extensors presumably contributed to the controlled lowering of the body. Thus, only a brief vertical impulse applied once per revolution was needed to maintain vertical equilibrium of the hoop whereas rotational equilibrium required impulses twice per revolution – one from the left hip abductors and one from the right.

Fig. 6 shows the angular velocities, moments and powers about the joints of the lower extremities during flexion and extension for Participant 2. This participant used a different mechanism than Participant 1 to provide vertical stability of the hula hoop. She applied a net plantiflexor (extension) moment at the left ankle that performed positive work, while there was a small burst of negative power and thus very little work performed by the plantiflexor moment of the right ankle. Thus, she regulated and sustained vertical displacement of the hoop using a plantiflexor moment about the left ankle while very little occurred about the right ankle.

In the case of Participant 2, the involvement of the flexor and extensor moments about the hips was also important in sustaining oscillations of the hoop. The flexors and extensors alternated between concentric and eccentric work, performing net positive work by the right hip moment and both positive and negative work by the left hip moment. The hip flexion moment performs its positive work simultaneous with the left plantiflexion
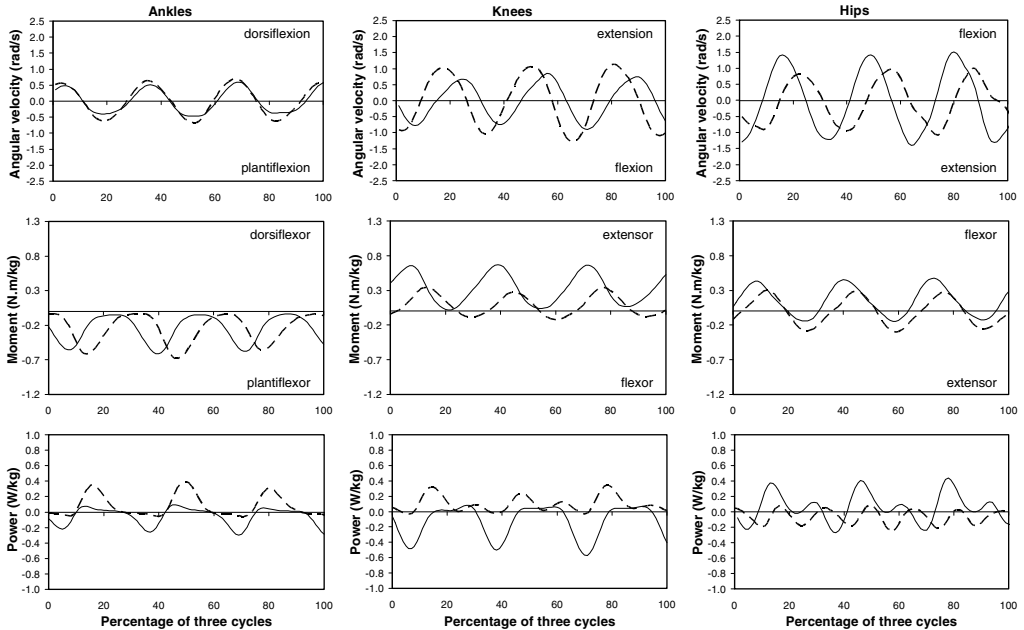
Fig. 7. Flexion/extension angular velocities (top row), moments (middle row), and powers (bottom row) of the ankles (left column), knees (middle column), and hips (right column) during hula hooping (Participant 3). Left side represented by bolded dashed line, right side by thin solid line. Ankle plantiflexor moments and angular velocities (extension) are considered negative, ankle dorsiflexion (flexion) positive. For the knees extensor moments and velocities are positive, flexor negative; at the hip, flexion moments and velocities are positive, extensor negative.

moment presumably to allow for the hip to move vertically but maintain the upper body's vertical position. In other words, extension at the ankle can cause upward displacement of the entire body but by flexing at the hip the upper body remains stationary. Another finding warranting mention is that both hip moments were concurrent, a strategy that was previously proposed by Balasubramaniam and Turvey (2004) as important to successful hula hooping. In summary, Participant 2 utilized a strategy that incorporated the left ankle plantiflexion and both hip flexion moments in maintaining hoop oscillations, while there was little involvement from the knee moments of force.

Fig. 7 shows the angular velocities, moments and powers for flexion/extension of the ankle, knee, and hip during hula hooping for Participant 3. As shown in the figure, there were plantiflexion (extension) moments at both ankles. Furthermore, moment power analysis revealed that the plantiflexion moment at the left ankle performed net positive work, whereas those at the right ankle performed net negative work. Similarly, the extensor moments of the left knee performed positive work throughout the trials while those of the right knee performed predominantly negative work. These results imply that the moments and powers performed about the ankle and knee joints of the left leg contributed to the vertical impulse by lifting the COM. Conversely, those at the right knee and ankle performed predominantly negative work, implying that the extensor musculature of the right leg aided in the controlled lowering of the body's COM. On the other hand, both hip flexor and extensor moments contributed bursts of positive and negative work but
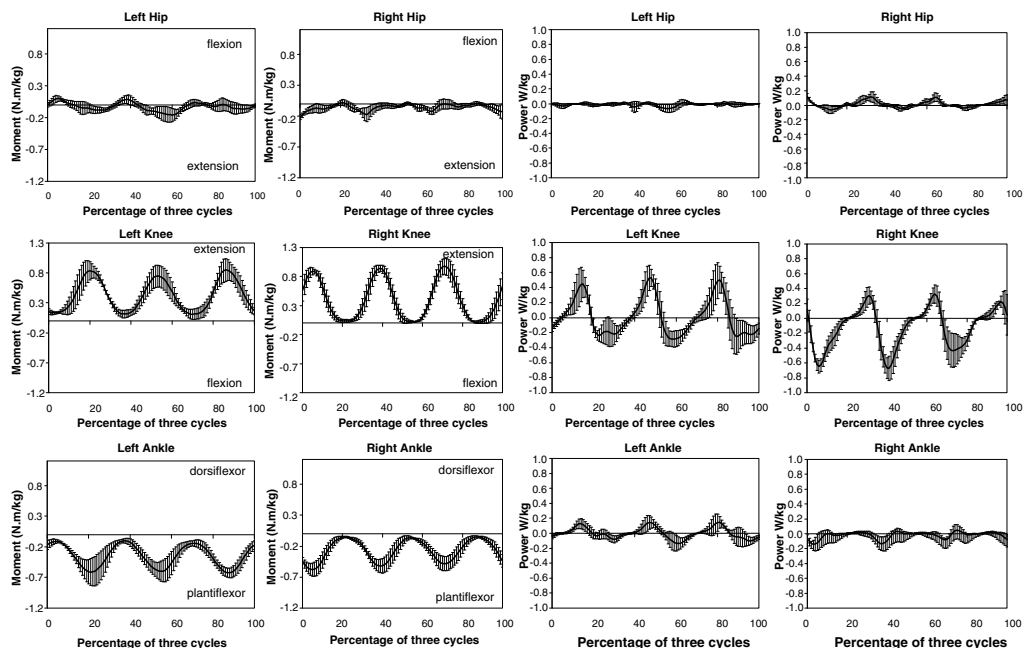
Fig. 8. Flexion/extension moments and powers of the right and left ankles, knees, and hips during hula hooping (Participant 1). Error bars (± 1 SD) demonstrate within-subject variability. Ankle plantiflexion moments and angular velocities (extension) are considered negative, ankle dorsiflexion (flexion) positive. For the knees extensor moments and velocities are positive, flexor negative; at the hip, flexion moments and velocities are positive, extension negative.

in amounts intermediate as compared to the other two participants. As such, Participant 3 adopted a balanced strategy, incorporating a plantiflexor moment at the ankle, extensor moment at the knee and flexor and extensor moments at the hip.

As demonstrated in the figures accompanying this discussion, hula hooping is a complex and variable task. Figs. 5–7 demonstrated that the participants adopted three different strategies in maintaining hoop oscillations despite equivalent experimental conditions. For instance, Participant 1 relied almost exclusively on an extensor moment at the knee, the strategy described by Balasubramaniam and Turvey (2004), who found by means of the dynamical systems theory that a smaller hoop led to increased involvement of the knee to adjust the vertical displacement of the hoop. However, the balanced strategy adopted by Participant 3 and the ankle-hip strategy adopted by Participant 2 fail to agree with the results previously reported in the literature. In fact, rather than demonstrating increased involvement of the moments of the knee, Participant 2 adopted a strategy whereby the knee extensor moment contributed little in the way of mechanical work. That is, the requisite vertical component of dynamic equilibrium was sustained through ankle plantiflexion rather than knee extension. In this regard, the participant adopted a slightly different strategy but was nevertheless capable of maintaining sustained oscillations of the hoop. Moreover, as demonstrated in the flexion/extension figures that accompany this discussion, Participant 1 was the only participant to demonstrate a net extensor moment that produced meaningful bursts of power at the knee. As such, she was likely to have adopted a strategy

characterized by greater knee flexion. Though an analysis of explanatory mechanisms underlying the observed kinetics was not of primary concern, such a strategy would serve to increase the distance between the knee joint center and ground reaction force, thereby increasing the magnitude of the extensor moment at the knee. Regardless, the results show that Participant 1 demonstrated an alternative strategy when compared to Participants 2 and 3, but was nevertheless successful in sustaining the hoop's dynamic equilibrium.

We expected the results of an inverse dynamics analysis that considered the specific contribution of individual joints and the underlying causes of motion would yield discrepant results compared to the abstract dynamical systems theory since the dynamical systems theory is only concerned with describing the kinematics of the task. Conversely, a kinetic analysis examines the mechanical sources underlying the observed motion. As demonstrated in the present results, for example, in Figs. 5 and 6, the flexion and extension patterns observed at the hip joint could be quite similar despite marked differences in the underlying kinetics. The results presented within this paper confirm the arguments offered by Balasubramaniam and Turvey (2004) with regards to the primacy of the hip in maintaining the angular motion of the hoop, though strategies used to sustain vertical equilibrium of the hoop were variable between participants. Therefore, it would seem that the knees are not solely responsible for the maintenance of vertical equilibrium. Though this appeared to be the case for one subject (Participant 1), the other participants adopted slightly variant strategies, relying on an ankle-hip strategy (Participant 2) and a balanced strategy where there was contribution from all three joints (Participant 3). Thus it would seem that inverse dynamics and dynamical systems theory, though concerned with different questions, complement one another when attempting to understand complex movements such as hula hooping.

As a result, we conclude that an inverse dynamics and power analysis present an alternative and complementary explanation of hula hooping by revealing the histories of the moments of force in the hula hooping task. Furthermore, this novel task demonstrated the danger of averaging across participants when participants employ different strategies. The obvious limitation of this research was limited sample size. Therefore, the reader should exercise caution when interpreting the present results. Further, this research documented the kinetics of hula hooping using different participants than those reported in Balasubramaniam and Turvey (2004). However, consistent eligibility criteria and methodological stringency would likely have led to congruent results should the kinetic analysis have been undertaken in the previous paper.

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