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Substantiating appropriate motion capture techniques for the assessment of Nordic walking gait and posture in older adults

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Abstract:	Background: Nordic walking (NW) has become a safe and simple form of exercise in recent years, and in studying this gait pattern, various data collection techniques have been employed, each with positives and negatives. Objective: 1) To determine the effect of NW on older adult gait and posture and 2) to determine optimal use of different data collection systems in both short and long duration gait and posture analysis. Methods: Gait and posture during NW and normal walking were assessed in 17 healthy older adults (age: 69 ± 7.3). Participants performed two trials of 6 Minute Walk Tests (6MWT) (1 with poles (WP) and 1 without poles (NP)) and 6 trials of a 5m walk (3 WP and 3 NP). Motion was recorded using two systems, a 6-monitor APDM accelerometry system and an 8-camera 3-dimensional motion capture system, in order to quantify spatial-temporal, kinematic, and kinetic parameters. Results: With both systems, participants demonstrated increased stride length and double support and decreased gait speed and cadence WP compared to NP (P<0.05). Also, with Vicon, larger single support time was found WP (P<0.05). With 3-D capture, smaller hip power generation and moments of force were found at heel contact and pre-swing as well as smaller knee power absorption at heel contact, pre-swing, and terminal swing WP compared to NP, when assessed over one cycle (P<0.05). Also, WP yielded smaller moments of force at heel contact and terminal swing along with larger moments at mid-stance of a gait cycle (P<0.05). No changes were found for posture. Conclusions: NW seems appropriate for promoting a normal gait pattern in older adults. Three-dimensional motion capture should primarily be used during short duration gait analysis (i.e. single gait cycle), while accelerometry systems should be primarily employed in instances requiring longer duration analysis such as during the 6MWT.

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Journal of Visualized Experiment Cover Letter

This work should be published in JoVe's unique multimedia format because with Nordic walking gait analysis, various types of equipment have been used, with minimal consensus amongst them. The purpose of this work is to determine the appropriate and optimal techniques and equipment to use during Nordic walking analysis and to minimize the variability within such protocols.

We are confident that this manuscript will meet the high standards of you Journal and if it's the case, it would be truly appreciated if the MS could be "accepted" by October 15th, on time for the Natural Sciences and Engineering Research Council of Canada (NSERC) NSERC grant application deadline.

The author contributions are as follows:

- Christopher Dalton (first author): idea conception/design, data collection, data analysis, manuscript writing
- Dr. Julie Nantel (corresponding author): idea conception/design, data analysis, manuscript review

We received assistance from Leyla Omeragic (email: leyla.omeragic@jove.com) during the submission process.

Lastly, the following is a list of 6 peer reviewers, including names, institutions, and emails:

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If there is anything else that is required, please do not hesitate to contact me by email at cdalt033@uottawa.ca or Dr. Julie Nantel by email at jnantel@uottawa.ca.

Sincerely,

Christopher Dalton and Julie Nantel.

TITLE:

Substantiating appropriate motion capture techniques for the assessment of Nordic walking gait and posture in older adults

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Nordic walking, Gait patterns, Posture, Accelerometry, 3-Dimensional motion capture, Older adults

SHORT ABSTRACT:

The aim was to substantiate optimal use of data collection techniques for Nordic walking gait and posture analysis. Three-dimensional motion capture should be used during short duration analysis (i.e. single gait cycle), while accelerometry should be employed for longer duration analysis (i.e. repeated cycles) like a 6 Minute Walk Test.

LONG ABSTRACT:

Nordic walking (NW) has become a safe and simple form of exercise in recent years, and in studying this gait pattern, various data collection techniques have been employed, each with positives and negatives. The aim was to determine the effect of NW on older adult gait and posture and to determine optimal use of different data collection systems in both short and long duration analysis. Gait and posture during NW and normal walking were assessed in 17 healthy older adults (age: 69 ± 7.3). Participants performed two trials of 6 Minute Walk Tests (6MWT) (1 with poles (WP) and 1 without poles (NP)) and 6 trials of a 5m walk (3 WP and 3 NP). Motion was recorded using two systems, a 6-sensor accelerometry system and an 8-camera 3-dimensional motion capture system, in order to quantify spatial-temporal, kinematic, and

kinetic parameters.

With both systems, participants demonstrated increased stride length and double support and decreased gait speed and cadence WP compared to NP ($P<0.05$). Also, with motion capture, larger single support time was found WP ($P<0.05$). With 3-D capture, smaller hip power generation and moments of force were found at heel contact and pre-swing as well as smaller knee power absorption at heel contact, pre-swing, and terminal swing WP compared to NP, when assessed over one cycle ($P<0.05$). Also, WP yielded smaller moments of force at heel contact and terminal swing along with larger moments at mid-stance of a gait cycle ($P<0.05$). No changes were found for posture.

NW seems appropriate for promoting a normal gait pattern in older adults. Three-dimensional motion capture should primarily be used during short duration gait analysis (i.e. single gait cycle), while accelerometry systems should be primarily employed in instances requiring longer duration analysis such as during the 6MWT.

INTRODUCTION:

Nordic walking (NW) is regarded as a simple and safe form of fitness walking using specially designed poles[1]. It is suggested that poles provide added stability, improve posture, and reduce joint stress of the lower extremities. However, limited or contradictory evidence exists regarding joint loading and postural alignment. On one hand, Schwameder et al.[2], Willson et al.[3], and Koizumi et al. [4] report improvements in kinematic measures and/or reductions in ground reaction, compression, and shear forces with their pole walking studies. On the other hand, declining kinematic measures and increased joint loading in terms of braking/propulsive forces and moments of force have been reported by Hansen et al.[5], Stief et al.[6], and Hagen et al.[7] while pole walking. Additionally, claims of improved postural alignment appear to have gone entirely unsupported by scientific research to this point.

Similar to the contradictory results found with gait patterns, different methods and equipment have been employed in this line of research as well. Several studies have used 3-dimensional motion capture systems[4,6] and digital video cameras[2,5], all with force plates incorporated into the system, in order to adequately assess gait. While additionally, other studies have employed other means of assessing Nordic poling gait including use of electrogoniometry[7], electromyography (EMG)[8], and strain gauges mounted to poles[2,9]. With the technique utilized in this protocol, it presents the specific advantage of being able to demonstrate a more appropriate representation (i.e. repeated gait cycles) of an individual's Nordic poling gait over alternative techniques that have focused more on short durations and single gait cycles. Also, this method uses accelerometry, a valid tool, which to this point has been sparsely used in Nordic walking research. Depending on the aim of individual research projects, the application of this protocol may be appropriate for situations as outlined in this protocol, particularly for short and long duration gait. It is important to note that both motion capture and accelerometry are suitable for obtaining a variety of gait characteristics including: spatial-temporal (e.g. stride length, gait speed, etc.), kinematic (e.g. range of motion), and kinetic (e.g. forces, power outputs, etc.) parameters.

And despite the use of these various pieces of equipment, only short duration gait events (i.e. single gait cycle) have been assessed, leaving questions in regards to best assessing longer duration gait (i.e. repeated gait cycles). Therefore, the rationale for the development and use of this technique is based upon the importance of fashioning a complete picture of Nordic poling gait.

The purpose of this study was two-fold. First, the primary goal is to determine and substantiate the use of both accelerometry systems and 3-dimensional motion capture systems in the assessment of gait and posture over both short and long durations. Secondarily, the goal is to determine the overall effect of Nordic walking poles on gait patterns including spatial-temporal and kinetic measures as well as postural alignment of older adults. To date, minimal research has focused on older adult NW and of that which has been published, function (i.e. strength, balance, flexibility) has represented the primary outcome variables. Therefore, knowledge pertaining the role of walking poles on measureable gait variables is needed and can provide insight into how poles can play into our gait patterns as we age.

PROTOCOL:

This study was performed in accordance with the guidelines of the Research Ethics Board of the University of Ottawa.

1. Screening Procedure

1.1) Provide PowerPoint presentations to local area walking groups and post recruitment posters at community centers and public facilities in order to recruit a group of active, community-dwelling older adults.

1.2) Upon initial visit, first greet the participants, introduce them to the laboratory, and provide them time to change into appropriate attire (i.e. shorts, t-shirt, and running shoes). Once ready, provide each participant with an in-depth study description, obtain written informed consent, and screen each individual for study eligibility using various questionnaires.

NOTE: Inclusion criteria includes: 55-80 years of age, novice to Nordic walking (NW), no neurological conditions, no cognitive impairments, no cardiac conditions, no previous injury or surgery affecting gait and upper extremity movement, and the ability to walk unaided.

1.2.1) Have the participant complete a General Health and Physical Activity Questionnaire and the Physical Activity Readiness Questionnaire (PAR-Q) in order to confirm age, activity level, any existing neurological conditions, and briefly assess cardiac health.

1.2.2) Next, have them complete a self-reported postural stability and falls questionnaire (adapted from Ashburn et al.[10]) to determine fall prevalence, if applicable. Lastly, complete the Montreal Cognitive Assessment (MOCA) with each subject in order to control for mild cognitive impairment[11], constituting a minimum score of 26 out of 30.

2. Pole Set-up and Nordic Walking Instruction

2.1) Provide each participant with a set of poles, and instruct them on how to adjust the poles to an optimal length relative to their height. Ensure that the adjustment corresponds to approximately 65% of the individual's body height.

2.1.1) Provide each participant with the following instructions regarding pole adjustment. Ask the participants to stand tall, have the participants place the pole tip in front of the toes, instruct the participants to place the elbow and forearm next to the body, and ask the participants to lengthen the poles so the elbow forms an approximate 90° angle next to the body. Finally, securely tighten the poles and angle the boot tips backwards.

2.2) Instruct the participant the following 4 basic steps in order to minimize the amount of information to process and ensure a thorough understanding of technique[12]. Allot approximately 30 minutes for instruction and subsequent practice of the technique.

NOTE: Nordic walking instructions are to be given by a certified Nordic pole walking instructor.

2.2.1) Before securing the wrist straps, instruct the participant to place their poles behind the lower back and stand tall. Ask the participants to stand with their chest tall and the shoulders relaxed.

NOTE: Explain to the participant that this is done to gain an understanding of the required upright body posture for Nordic walking.

2.2.2) Have each participant secure the wrist straps, place the pole tips behind them, and relax their arms at their sides. While keeping their hands open (i.e. not grasping handles), instruct the subject to begin walking with minimal arm swing for approximately 100 meters.

NOTE: At this stage, the poles are simply trailing behind the participant.

2.2.3) While still keeping the hands open and dragging the poles behind them, instruct the participant to begin walking faster. Ask the participants to visualize bringing their hand up as if they are about to shake someone's hand.

NOTE: At this phase, explain that the goal is to promote the natural reciprocal and rhythmic actions of the arms and legs during gait.

2.2.4) Finally, as the arm swings forward, have the participant gently grasp the handle and apply a force against the ground. With each arm swing, instruct the individual to slightly lift the poles off the ground and firmly plant them with each subsequent stride.

NOTE: At this stage, explain that the applied force aids in progression of gait and provides resistance to the upper body musculature.

3. Data Collection and Testing Protocol

3.1) Using a standard tape measure, weight scale, and caliper, take the participant's anthropometric measurements, including height, weight, inter-ASIS distance, left and right leg lengths, knee widths, ankle widths, shoulder offsets, elbow widths, wrist widths, and hand thicknesses.

3.1.1) Using a tape measure, measure each leg length as the distance from the anterior-superior iliac spine (ASIS) to the center of the medial malleolus as well as the distance between the left and right ASIS (i.e. inter-ASIS distance).

3.1.1.1) Next, measure the widths of each joint using a caliper by finding the distance between the bony prominences (e.g. condyles) of each joint. Lastly, measure the height and weight of the participant using a standard tape measure and scale, respectively.

3.2) In order to assess gait patterns (e.g. spatial-temporal measures) and postural alignment over a long period of time, use an accelerometry system for data collection during the 6 Minute Walk Test (6MWT), which is a valid and appropriate test in the assessment of older adult physical endurance[13].

3.2.1) For the accelerometry system, ensure that it is comprised of at least 6 sensors, each with accelerometers and gyroscopes incorporated into them in order to measure both the acceleration (g) and angular velocity (deg/s) of each specific body segment.

3.2.1.1) Prior to placement on the participant, ensure that all sensors are securely docked to the system's docking station in order to synchronize them and calibrate the system, and ultimately relay precise data measurements[14].

3.2.2) Attach the sensors using adjustable hook and loop straps, secure the sensors to the wrists, ankles, lumbar spine (L5) and trunk and collect at a sampling rate of a minimum of 100 Hz.

3.2.2.1) When placing the sensors, ensure that they are oriented according to the system guidelines. Position the ankle sensors anteriorly. Position the wrist sensors posteriorly (when in anatomical position). Position the trunk sensor atop the sternum, and position the L5 sensor directly at the L5 vertebrae.

NOTE: Kinematic data is wirelessly transmitted from these sensors to an access point, which is used to precisely time the transmission of the synchronized data.

3.2.3) Fit the participant with the 6 sensors and ask them to perform two trials of the 6MWT, one with poles and one without. Randomly assign these two trials to control for order effect.

3.2.4) Instruct the participant to walk back and forth along a 25-m walkway at a self-selected speed for the 6MWT, for both with and without poles. At this time, be sure to click 'Start' to begin data collection with the accelerometry system.

NOTE: During pole trials, provide further instruction to the participant to implement their poling instruction.

3.3) Finally, assess short duration gait events using a 3-dimensional motion capture system collecting at a minimum of 100 Hz, with two force plates embedded in the pathway. Synchronize the force platforms with the motion capture system, ensure that the force platforms are zeroed to prevent noise in the data, and ensure that they are collecting at a sufficient sampling rate, for example 1000 Hz.

3.3.1) Synchronize the force plates to the motion capture system by first connecting them to the computer via the wires provided from the company. Second, directly within the motion capture system software, it is imperative to 'add' the force plates to the capture volume by entering the dimensions, sensitivities, sampling rates, and any other required information for the system.

3.3.2) Ensure that the force plates have been 'zeroed'. Do this in two steps: 1) right click on each force plate within the software and select 'Zero force plate' and 2) press the 'zero' button that is directly on the data acquisition box of the force plates.

NOTE: Ensure that the motion capture system collects real-time information from both the left and right legs from foot strikes on each force platform and allows for spatial-temporal, kinematic, and kinetic analysis.

3.4) Complete a dynamic calibration of the system (aimed at defining the capture volume that is to be used during data collection). To do this, wave a 3-marker wand in a controlled manner through the capture space. Then perform a static calibration of the system to set the global coordinate system (i.e. reference point of 0, 0, 0 (x, y, z)by placing a 4-marker L-frame at that specified reference point and select **'Set Volume'** within the computer software.

NOTE: The dynamic calibration later assists in the reconstruction of the 3-dimensional position of 39 reflective markers used for this model.

3.4.1) Fit the participant with the 39 reflective markers, attaching them using double-sided tape and placing them on specific anatomical landmarks including: second metatarsals, lateral malleoli, calcanei, left and right mid-shank, lateral femoral condyles, left and right mid-thigh, ASIS, PSIS, T10, C7, right back, clavicle, sternum, acromion processes, left and right mid-humerus, lateral epicondyles, left and right mid-forearm, medial and lateral wrists, second metacarpals, anterior-lateral head, and posterior-lateral head.

3.4.2) Instruct the participant to then perform 6 trials of a 5 meter walk through the systems capture volume, three with poles and three without. Randomly assign these trials to control for order effect and provide the same instruction as per the 6MWT.

4. Data and Statistical Analysis[14].

4.1) During analysis of the 6MWT, remove all turns during the trial in order to account for strictly steady state walking After removing the turns, use the system software to extract the spatial-temporal measures, trunk range of motion (ROM) in all places, and trunk velocities in all planes. **NOTE:** This is done automatically during this protocol through algorithms used by the system itself.[14] The steps to extract the necessary dependent variables within this system are listed below.

4.1.1) Using the accelerometry system software, first click on **'Monitor Data'**, select the appropriate time stamped trials that have been collected, right click on the trials, and select **'Convert to CSV'**. After doing this, open the CSV file and ensure that data from all 6 sensors has been exported for further analysis.

4.2.2) Next, select the trial again and click **'Export to PDF'**. Observe the system generate a PDF report with a number of variables. From here, extract variables that are desired for the study, in this case, spatial-temporal and kinematic measures.

4.2) For 3-dimensional motion capture, filter all trials using a fourth-order zero lag Butterworth filter for analog devices with a cut-off frequency of 10 Hz as well as a Woltring filter for the marker trajectories with a 15mm MSE predicted value. To do this, attach the **'Butterworth and Woltring'** filtering options to the operations pipeline within the system software, select the aforementioned cut-off frequencies and MSE values, and click '**Run'**.

4.2.1) Add an **'Export to ASCII file'** operation to the operations pipeline within the system and select **'Run'**. Save the newly exported ASCII (spreadsheet) worksheet to the computer.

4.2.2) Open the **exported ASCII files** and within each file, locate the power outputs and moments of force (i.e. kinetics) for each of the lower extremity joints, including the ankle, knee, and hip.

NOTE: Using the minimum and maximum functions within the worksheet, calculate the upper and lower peaks corresponding to the different phases of a single gait cycle (e.g. A1, K1, H1, etc.) as outlined by Winter[14].

4.2.3) Next, extract the spatial-temporal measures using the specific system software, which in this instance, is automatically calculated through system algorithms and from anthropometric measurements. To extract the specific variables, first import the desired trial into the system software, select **'Events'**, and click on the desired variable to obtain the variable average from each trial.

4.3) Lastly, using the ASCII files, locate the trajectories for the C7 marker as well as the sacral/pelvic markers. Using these trajectories, calculate postural alignment as the differential between these markers and trajectories in both the medial-lateral and anterior-posterior directions.

4.4) Open statistical software and import the specific trial. First, using Shapiro-Wilks test for normality, ensure whether data is normally distributed.

4.4.1) To compare with and without poles, use paired t-tests when data is normally distributed and Wilcoxon Signed Rank Tests when skewed. Use Holm-Sidak multiple pairwise comparison procedures when necessary. Significance level is set at $p < 0.05$.

REPRESENTATIVE RESULTS:

Spatial-Temporal Gait Parameters

When walking with Nordic walking poles and assessed using motion capture and force plates, stride length ($p < 0.01$), double support time ($p < 0.001$), and single support time ($p < 0.001$) are all significantly longer compared to walking without poles. In addition, gait speed ($p < 0.05$) is significantly slower and cadence ($p < 0.001$) is significantly smaller with poles compared to without in older adults. Further, when examining gait over a longer duration walk with the 6MWT and using accelerometry, similar results are noted with a longer stride length ($p < 0.001$) and double support time ($p < 0.001$) as well as a significantly slower gait speed ($p < 0.001$) and smaller cadence ($p < 0.001$) (Table 1).

Lower Extremity Joint Kinetic Analysis

Kinetic measures are solely assessed using 3-dimensional motion capture.

Hip Joint

When using poles, significantly smaller hip power generation is seen at heel contact (H1) ($p < 0.05$) as well as at pre-swing (H3) ($p < 0.01$) compared to walking without poles (Figure 1). To coincide with these reductions in hip power generation, the moment of force while walking with poles is significantly smaller at both heel contact ($p < 0.05$) and pre-swing ($p < 0.05$) compared to without poles.

Knee Power Generation/Absorption

When using poles, significantly smaller knee power absorption is seen at heel contact (K1) ($p < 0.05$), at pre-swing (K3) ($p < 0.001$), and at terminal swing (K4) ($p < 0.001$) compared to walking without poles (Figure 2). Additionally, with poles significantly smaller moments of force are found at heel contact ($p < 0.001$) and at terminal swing ($p < 0.001$) and significantly larger moments of force at mid-stance ($p < 0.01$) compared to without poles.

Ankle Power Generation/Absorption

There are no significant power output or moment of force differences at the ankle joint at either heel contact (A1) or toe-off (A2).

Postural Analysis

There are no significant differences in trunk range of motion when using accelerometry in any of the three planes of motion (i.e. frontal, sagittal, and horizontal) or with motion capture in the frontal and sagittal planes.

The results found in this research coincide with previous research on the same topic using similar motion capture systems. These results demonstrate that this technique and use of both motion capture and accelerometry can be widely appropriate in the assessment of gait and posture.

FIGURE LEGENDS:

Figure 1: Peak hip power over a single gait cycle

Figure 1 represents a typical hip power profile in watts per kilogram of body weight over one single gait cycle (i.e. heel strike of one foot to the next heel strike of that same foot) to compare with poles (Red) to without poles (Blue). The arrows at H1, H2, and H3 phases are indicative of the changes in power generation/absorption in comparing with poles to without poles, with the asterisks indicating a significant difference between the two.

Figure 2: Peak knee power over a single gait cycle

Figure 2 represents a typical knee power profile in watts per kilogram of body weight over one single gait cycle (i.e. heel strike of one foot to the next hell strike of that same foot) to compare with poles (Red) to without poles (Blue). The arrows at K1, K2, K3, and K4 phases are indicative of the changes in power generation/absorption in comparing with poles to without poles, with the asterisks indicating a significant difference between the two.

Table 1: Spatial-temporal means and standard deviation for both data collection systems

Table 1 represents the various spatial-temporal measures obtained from both accelerometry and motion capture systems. Both crosses and asterisks represent a significant difference between with poles and without poles for each respective system, with crosses specifically representing significant difference at $p<0.01$ and asterisks representing a significant difference at $p<0.05$.

DISCUSSION:

The importance of maintaining consistency in terms of pole use is critical within this protocol. Particularly, appropriate steps for proper poling technique as well as proper pole set up are important to maintain consistency across different studies. Therefore the guidelines and instructions of a specific Nordic walking organization should be adhered to for protocols such as this. Additionally and particularly when using accelerometry, use of a full body set of tri-axial monitors is important to obtain a complete understanding of the subject's full body motion (e.g. gait and posture) including acceleration and rotation of each specific body segment. Such a system can and should be primarily employed in instances as per this protocol, using a relatively long walkway (e.g. 25m) in order to account for long duration events as well as minimize the number of turns to account for primarily steady state walking. This could be particularly important when using validated gait tests such as the 6MWT[13] within both clinical and research settings.

Further, motion capture systems have been reported as appropriate equipment in studying short duration events such as single gait cycles[16] and should be used as such, as is the case with the second portion of this protocol. To ensure accuracy of this system, it is imperative to perform proper static and dynamic calibrations of the system to set the capture volume and more importantly the global coordinate system required for 3-dimensional reconstruction of the reflective markers. In order to assess both gait as well as postural alignment, a full body marker set (e.g. Plug-in Gait model) is necessary as the positions and displacements of the hip (PSIS and Sacral) and spinal (C7) markers are critical in the analysis and measurement of trunk range of motion (ROM) in the anterior-posterior (AP) and medial-lateral (ML) directions. And lastly, the forces plates integrated with the system should be collecting at a sufficient sampling rate, for instance, 1000 Hz from this protocol. Sampling rate can be changed from study to study, however, researchers must be certain not to violate the Sampling Theorem, which states "the process signal must be sampled at a frequency at least twice as high as the highest frequency present in the signal itself"[17].

Depending on equipment availability within different laboratory setting, various accelerometry systems and motion capture systems may be used, provided they allow for adherence to the critical steps of this protocol. For example, if unable to use a tri-axial monitor system that has both acceleration and gyroscope readings or if the lab space is insufficient to incorporate a long walkway, use of this system may not be entirely adequate for the assessment of one's gait and posture. Similarly, with motion capture systems, use of a lower-body model for each participant is adequate in the assessment of various gait characteristics, however, lower-body models would fail to appropriately assess postural alignment as some of the necessary hip and spinal markers may be missing to calculate trunk ROM. Also, if using this protocol to examine specific conditions (e.g. knee osteoarthritis or ACL injury), use of different or modified marker sets such as that used by Ali, Rouhi, and Robertson[18] may be used to create a more complete assessment of the knee for such conditions. Additionally, as this study is focused on older adults only, the protocol can benefit from the addition of a control group for comparison purposes, however, this is largely dependent on the populations for each individual study. Depending on the population, a control group (e.g. young adults) may contribute to further understanding how gait and postural alignment changes, both with and without the use of Nordic poles. Also, to better understand the role that the poles themselves play during gait, use of strain gauges could be incorporated. Following a technique previously used on healthy young adults by Jensen and colleagues[9], placement of a strain gauge on each of the poles could assist in the assessment of kinetic gait measurements. And lastly, following a technique employed by Shim and colleagues[8], using electromyography (EMG) with this protocol can aid in understanding the specific muscle activation patterns of both the upper and lower extremities during Nordic walking.

The originality of this protocol resides in the fact that it provides the guideline for state of the art gait analyses in two very different set-ups. Therefore, this gives rational and viable options for researchers and clinicians to choose from when deciding on the protocol that will serve best the purpose of their analysis. To reiterate, with the 3-dimensional motion capture system, the goal is to study short duration events as is the case with a single gait cycle, while accelerometer systems are used in this instance to study gait as a whole over a longer period of time. Different

3-dimensional motion capture systems as well as video cameras, all with force plates integrated into them have been commonly used in the assessment of Nordic walking gait[3–6]. Stief et al.[6] used a 6-camera system to collect 5 poling and 5 non-poling trials in order to measure the kinematics (i.e. ROM) and kinetics (i.e. moments of force) about the hip, knee, and ankle joints. Similarly, a 10-camera system was used by Koizumi and coll.[4] with two force plates incorporated into it to obtain kinetic measurements from 10 Nordic walking trials in order to ultimately calculate shear and compression forces of the lower extremity joints and lumbar spine. Further, Hansen et al.[5] used a 5-camera digital video system to record movements, again with two force platforms embedded in the walkway in order to quantify kinetic variables including: compression forces, shear forces, ground reaction forces, and moments of force. Existing methods fundamentally point to the use of motion capture systems as widely accepted and largely appropriate for an accurate and efficient measure of an individual's gait patterns, albeit for short duration events.

Contrary to the commonality of motion capture, alternative methods such as the one used by Hagen et al.[7] have at times been employed. In this particular study, electrogoniometry and force plates are used to evaluate the spatial-temporal measures (e.g. stride length), lower extremity ROM, and kinetics, specifically the vertical force. They did also use an accelerometry system, however, it is a uniaxial monitor that was only placed on the right radial side of the wrist to measure wrist acceleration and assist in estimation of shock to the body. Beyond Hagen et al.[7] in recent years, Nordic walking gait has really yet to be examined using accelerometry. And further yet, research has yet to study longer duration gait events such as with the 6MWT. Just as motion capture is widely used for short duration events, accelerometry should become more of a staple in gait analysis, particularly over a lengthier period of time. If use of accelerometry is more widely recognized and valued in this respect, this may allow for a more representative evaluation of gait as it is performed on a daily basis.

Once the protocol is perfected, using both accelerometry and motion capture for Nordic poling gait analysis will help to create an assessment of gait in its entirety that could be representative of both short spurts of walking as well as longer. Moreover, such techniques may be employed with specific populations (e.g. Parkinson's disease) to gain a better understanding of how Nordic walking poles can affect not only a single stride, but also obtain a better representation of their gait from repeated strides. Also, if available in clinical practice, clinicians may be able to use accelerometry to more precisely measure a patient's gait during clinical assessment. Such systems are particularly user friendly and simplify data collection and analysis. Finally, looking at the effect of a Nordic walking intervention may be appropriate to coincide with this protocol. It is possible that learning the poling technique and then instantly performing laboratory testing may not result in an entirely accurate assessment. Instead, practice with the poles for a period of time (e.g. 8 weeks) may provide a better assessment of the effect of Nordic poles on gait and posture.

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On behalf of my co-author and myself, I would like to acknowledge Nordixx Canada for helping to fund this research, our participants for their time and patience, and our fellow colleagues,

Josée, Ria, Lei, and Nadia, for their help with various aspects of this study.

DISCLOSURES:

On the behalf of my co-author and myself, I state that there is no conflict of interest.

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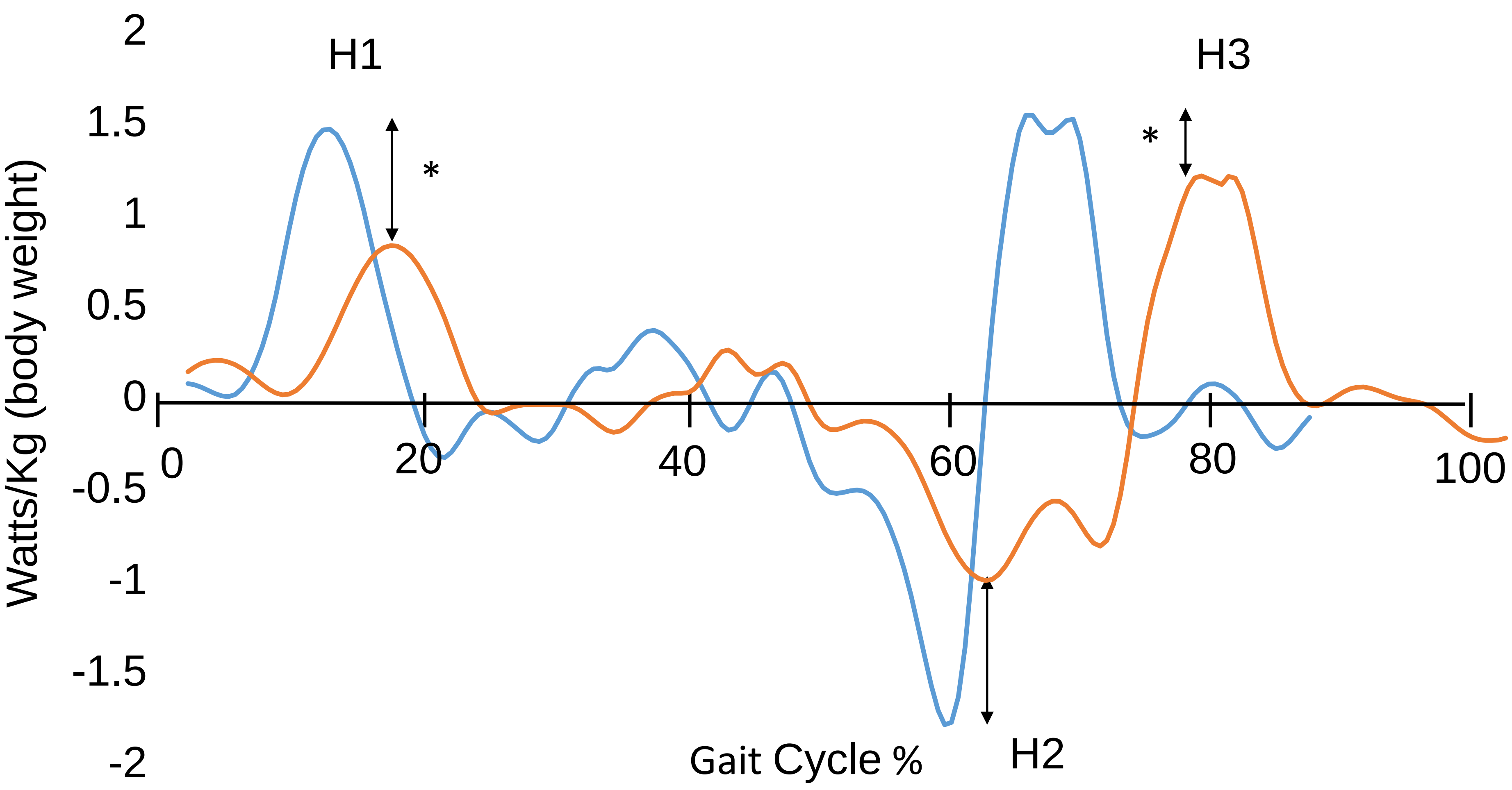
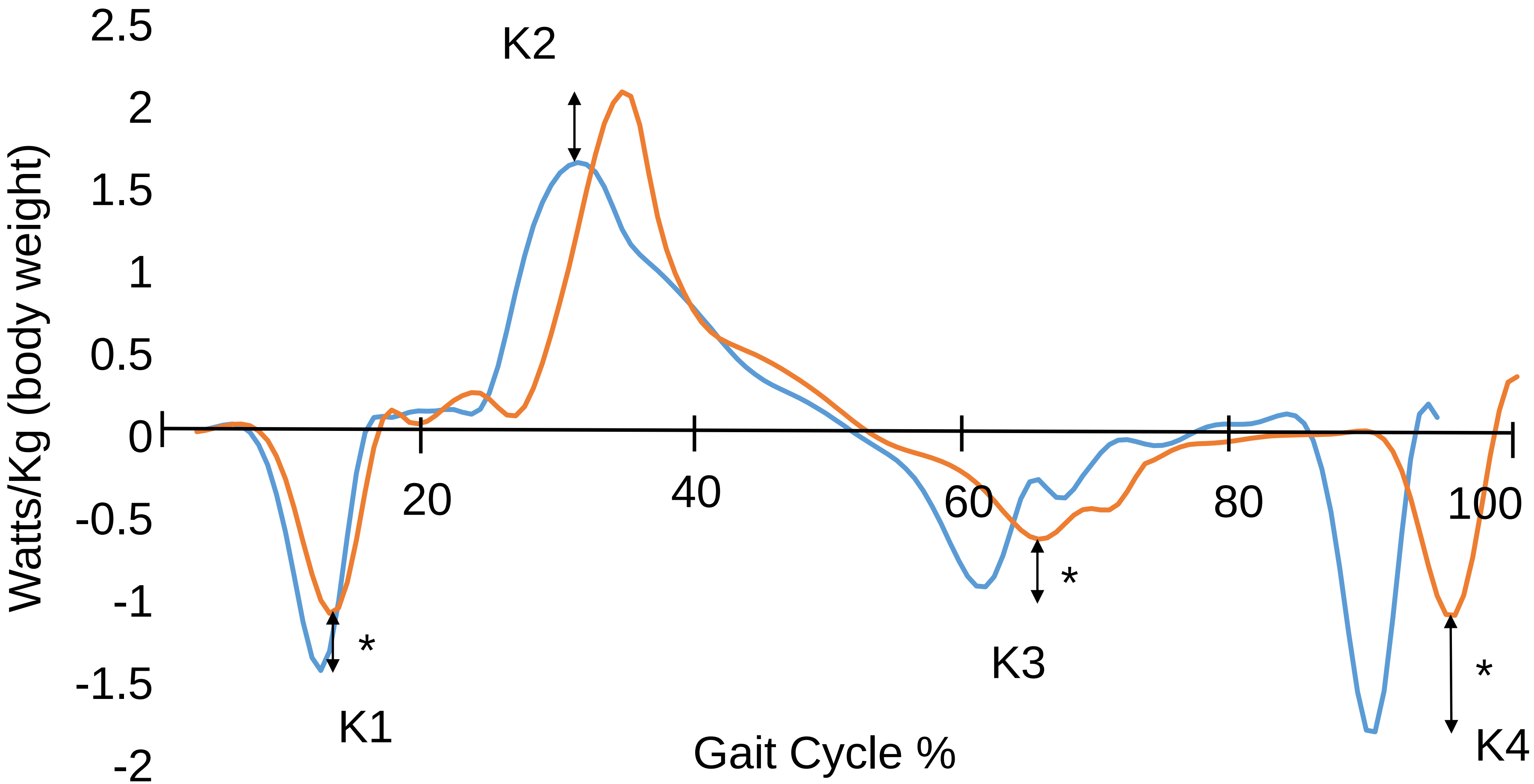

H1
H3
H2
*
*
Watts/Kg (body weight)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
20
40
60
80
100
Gait Cycle %


Watts/Kg (body weight)
2.5
2
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1
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-0.5
-1
-1.5
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20
40
60
80
100
Gait Cycle %
K1
K2
K3
K4
*
*
*

	VICON		APDM	
	With Poles	**Without Poles**	**With Poles**	**Without Poles**
Outcome Measures	**Mean ± SD**			
Stride Length (m)	1.39 ± 0.19	1.31 ± 0.21 †	1.47 ± 0.11	1.42 ± 0.11 †
Gait Speed (m/s)	1.08 ± 0.23	1.18 ± 0.20 *	1.25 ± 0.17	1.39 ± 0.14 †
Cadence (steps/min)	93.07 ± 10.90	108.78 ± 11.26 †	101.92 ± 12.17	117.82 ± 9.74 †
Double Support Time (s)	0.34 ± 0.06	0.28 ± 0.06 †	0.28 ± 0.07	0.22 ± 0.06 †
Single Support Time (s)	0.48 ± 0.05	0.41 ± 0.04 †	---	---

Name of Material/ Equipment	Company	Catalog Number	Comments/Description
Nordic walking poles	Nordixx Canada	Nordixx Global Traveler or Walker	Alternative poles may be used
APDM accelerometry system	APDM	Opal system	Alternative systems may be used
Vicon motion capture system	Vicon		Alternative systems may be used
Kistler force platforms	Kistler		Alternative platforms may be used
Vicon Nexus & Polygon	Vicon		Used in data analysis
14mm reflective markers	Vicon		Number or markers depends on model
Tape measure			
Weight scale			
Caliper			

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Signature:	[signature] Date: July 23, 2015

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Please find enclosed our reply to the reviewers' comments and a revised version of our manuscript. We would like to thank the reviewers for their valuable comments. We have made all the changes requested to clarify and improve our manuscript according to the reviewers' comments.

We are confident that this revised version is suitable for publication in JOVE.

Best regards,

Julie Nantel and Christopher Dalton.

COMMENTS:

-Short abstract – Please use complete sentences.

Complete sentences are now used throughout short abstract.

-Please copyedit the long abstract for typos. Also, please use complete sentences.

Edited and complete sentences are now used throughout the long abstract.

-2.1.1 – Please delete "3)"

This has been deleted.

•Formatting:
-Please make sure all steps are sequential. For instance, 3.2.2 is repeated.

The sequence for all of the steps has been double checked.

-Please bold all figure titles.

Figure 1 and Figure 2 titles have been bolded.

-References – Please abbreviate all journal titles.

All journal titles in the reference list have been abbreviated.

•Additional detail is required:
-3.2.2 – Are the sensors the same as the IMUs?

Editorial comments:
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Yes they are the same. To avoid confusion, we have removed the term IMU and solely refer to them as 'sensors'.

How is recording started or synchronized?

This has been added to section 3.2.4.

How are sensors attached?

This has been added to the MS. They are attached using adjustable Velcro straps.

-3.3 – How is the force plate calibrated here?

Once linked to the system, the operator must ensure that they are zeroed to be calibrated properly. This was added to the MS.

-3.3.1 – Please provide step-wise instruction for each calibration type if this is to be filmed. Otherwise, provide a citation.

We have added simple instructions

-3.3.2 – Which landmarks? How are markers attached?

The landmarks and therefore, positions of the sesnsors have been added to the MS. Also, they are attached using double sided-tape has been added as well.

-Table 1 – What do crosses and asterisks represent?

Indicated that they represent the $p<0.01$ and $p<0.05$ significance levels in comparing WP to NP.

-Figures – Please indicate in the legend what the asterisks and arrows indicate.

Indicated this within the 'Figure Legends' section.

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We have copyedited the manuscript.

Reviewers' comments:

Reviewer #1:

Manuscript Summary:

The manuscript presents a gait assessment study of 17 older adults during Nordic Walking. The authors investigated Nordic Walking with and without poles, and found differences in several gait parameters. Since the journal supports an unusual style of writing an article, the manuscript contains instructions like "Export to PDF" or "click on 'Run'". Therefore, I missed some technical parts of the manuscript.

Major Concerns:

N/A

Minor Concerns:

*In the protocol instruction was stated that the data of the 6 sensor node were synchronized. How was that done?

This is briefly described in section 3.2.2), in the 'NOTE' portion. It states the following: "**NOTE:** Kinematic data is wirelessly transmitted from these sensors to an access point, which is used to precisely time the transmission of the synchronized data." We also added to section 3.2.1), stating that the sensors are synced via the system's docking station.

And how was synchronization done with the data of the motion capturing system?

Editorial comments:

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This is briefly described in section 3.3), in the 'NOTE' portion. It states the following: "**NOTE:** Ensure that the motion capture system collects real-time information from both the left and right legs from foot strikes on each force platform and allows for spatial-temporal, kinematic, and kinetic analysis."

Which communication protocol did the authors used? Did the protocol handle data transmission failures? Were there sections of missing data?
*There is also the note that the turns were removed automatically. It would be interesting to learn how the algorithm works (maybe a reference will help).

The information regarding the algorithm is not provided by the company due to commercial exclusivity. However, a reference to the User guide was provided in section 4.1

Did the authors ensured correct accelerometer/gyroscope calibration?

Information regarding the synchronization of the sensors has been added to section 3.2.1), and defines that the sensors must be docked together and calibrated prior to use. Further details of the calibration algorithm can be found in the User Guide mentioned above.

*It would be interesting to learn how the participants were recruited for the study. Were these participants from a retirement home, or were they community-dwelling older adults, or recruited with a newspaper ad?

We have added a new 1.1) section to the manuscript that outlines the recruitment methods that should be used and populations that should be targeted for such a population. However, depending on the population being studied, these methods may be altered.

The recruitment method may have an influence in the results and may also bias the results. Some characteristics (weight, sex, etc.) would also be interesting.

As the focus of this journal has to do with methods, and not so much results, I am not sure where in the manuscript to place such characteristics. The goal of the paper is to substantiate the data collection techniques, regardless of the population being assessed, therefore I'm not sure that this is overtly important

*What happend to the questionnaires and to the assessment data? Are there some interesting results?

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The questionnaires were simply used to ensure that all participants met the study eligibility criteria. We did not run any correlations with any of the questionnaire data, therefore really don't have any major results from these.

Additional Comments to Authors:
N/A

Reviewer #2:
Manuscript Summary:
General comments:
The present deals with a very interesting approach to analyse gait patterns with an accelometry system. There are some methodological aspects I have to comment on, as the present version shows a lack of validity and reliability:
To my understanding, you argue that using an accelometry system will be suitable to compare NP with WP walking, especially if you conduct a field test. Following your argument, I would have expected a study concerning the validity of the accelometry/gyroscope system by comparing the system with the golden standard (3D-kinematics). You should do this comparison by using the 'limits of agreement' approach which was presented by Bland and Altman (1986). As you did not present any references according to the accelometry/gyroscope system, I suppose that these data are missing.

Bland JM, Altman DG Statistical methods for assessing agreement between two methods of clinical measurement Lancet. 1986 Feb 8;1:307-10. PMID 2868172
Bland JM, Altman DG Measuring agreement in method comparison studies Stat Methods Med Res. 1999 Jun;8:135-60. PMID 10501650

We appreciate reviewer 2's comment. However, the validation process of the system has been made prior to the commercialisation of the product and therefore was not at main goal of the present study. Furthermore, the rational behind using two systems to collect data is to complete the information relative to the gait pattern rather than duplicate it. Indeed, the traditional analysis using the optoelectronic system allows to quantify only short bout of gait while the accelerometer system allows to investigate longer trials. Therefore it was not our intention to compare these two systems. For more information regarding the validity and reliability of the system, please refer to the User guide.

Specific comments:

Editorial comments:
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Introduction
As you describe in the title of the manuscript and in the methods section, you compare NP with WP gait pattern in elderly people. This point is missing in the introduction. Please add some information why older people are your target group.

> We have added a few sentences as to why older adults were our main target group and what we hope to add to the existing literature. This is located at the end of the introduction, coinciding with our purpose statement.

Methods
The instrumentation and the validity of its use should be presented more precisely:
*Lines 188-90: Present more details about the accelerometry system. Which system did you use.

> Previous comments from the editor asked that we remove any commercial brands and names (e.g. Kistler, Vicon, etc.). Therefore, for the breadth of this journal, we are unable to include the type of force plate that was used, within the MS (according to the Editor). Although, it was an APDM accelerometry system that was used in this study.

Are there any studies on the validity and reliability of the system in gait analyses. If not, this would be a necessary point to include into your study, especially, as you compare gait pattern between NP and WP walking in elderly people.

*Lines 192/193: Include more information concerning the sensor placement. As mentioned above, you need a reference for this procedure. Otherwise, you should add a study about the reliability of this procedure.

> I have added more information pertaining to the placement of the sensors at all 6 landmarks. A reference to the User Guide has been added to the MS in section 4.1). Therefore, for more details please refer to previous comment on that topic and to the User guide.

*Lines 208-210: Which force plate did you use.

> Previous comments from the editor asked that we remove any commercial brands and names (e.g. Kistler, AMTI, Vicon, etc.). Therefore, for the breadth of this journal, we are unable to include the type of force plate that was used, within the MS (according to the Editor). Although, 2 Kistler force platforms were used in this study.

*Lines 237-240: Add information about the software you use. Is it a custom-made software?

Editorial comments:
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Once again, based on the previous editor comments, we cannot include the software used due to the use of commercial brands and names. Although, the software used was specifically from APDM and we used the algorithms within the software to extract a plethora of variables.

*Data and statistical analysis: It would be more reader-friendly if you would add a table with the parameters you calculated.

We recognize that including the results in a table could facilitate the reading. However, we were unsure whether a second table could be included in the MS. We do have a table (with lower extremity power outputs) ready and will leave it to the editor's discretion to decide whether or not this second table should be included.

*Statistical analysis: I recommend adding the limits of agreement concerning the kinematic parameters and Bland-Altman-plots.

References:
Cite only published papers or conference presentations. Reference 15 is not available.

We double checked to see if this reference was available by copying and pasting the link into the address bar of our search engine. When we did this, the reference was available for us.

Revise ref. 14 according to JoVE style.

We have revised this to fit JoVE style.

Major Concerns:
N/A

Minor Concerns:
N/A

Additional Comments to Authors:
N/A

Editorial comments:
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Editorial comments:

1. ***NOTE: Please download this version of the Microsoft word document (File name: 53926) for any subsequent changes.***
2. The authors have not submitted a response letter to the editorial and peer review comments with the previous revision. Please enclose a rebuttal or response letter. For this and the previous submission.

3. JoVE is unable to publish manuscripts containing commercial sounding language, including trademark or registered trademark symbols (TM/R) and the mention of company brand names before an instrument or reagent. Please remove all commercial sounding language from your manuscript and replace it with a more generic term as much as possible throughout the entire manuscript. All commercial products should be sufficiently referenced in the table of materials/reagents. Examples of commercial sounding language in your manuscript are PowerPoint, etc.

4. In step 3.3, how are the force platforms synchronized with the motion capture system? How are the force platforms zeroed? How are they collecting samples?

> We have added additional steps as to what is required for synchronizing the system and force plates, zeroing them, and a mention of when to input the sampling rates.

5. Text in step 3.3.1 is not written in imperative tense. Please split this in two steps.

> This has been changed into imperative tense. Also, due to the inclusion of the steps mentioned above (i.e. synchronization, etc.), we have renumbered the steps. Step 3.3.1) is now **3.4)**

6. Please split step 3.3.2 into two steps.

> This has been split into two steps. Also, due to the inclusion of the steps mentioned above (i.e. synchronization, etc.), we have renumbered the steps. Step 3.3.2) has been split into two steps and are now number **3.4.1) and 3.4.2)**.

Editorial comments:

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