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Coordination Indices between Lifting Kinematics and Kinetics

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Abstract

During a lifting task the movement of the trunk can account for the majority of the external moment about the ankle. Though the angle of trunk flexion and the external moment about the ankles are roughly correlated, this correlation can be reduced by various segmental dynamics and momentums with the upper/lower extremities. Two methods are proposed in this technical note for describing the relationship between the kinematics and the kinetics of a lifting motion. The first relies on the phase plane analysis technique and explores the relative phase angle between the kinematic characteristics of lifting motion (i.e., trunk motion in the sagittal plane) and the kinetic characteristics of lifting motion (i.e., the net external moment). The second technique employs the moving correlation technique that assesses the level of coordination between the net external moment and the angle of the torso in the sagittal plane. In this paper, these methods are applied to a dataset of lifting motions of obese and normal weight participants to explore the utility of these modeling approaches on the assessment of potential risk in the lifting task due to obesity.

Keywords: trunk flexion; external moment; coordination

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1 Introduction

Under static conditions the correlation between the trunk flexion angle and external moment is roughly linear since the trunk mass accounts for the majority of the body mass depending on the location of the center of gravity (Enoka, 1988). A kinematic and kinetic analysis of a dynamic sagittally symmetric lift reveals very similar patterns where large trunk flexion is concordant with large bending moment measured from the ground (Figure 1). This figure also shows that the external moment can be significantly influenced by the acceleration profile based on the dynamics of the lifting motion (Chaffin, 1999; Toussaint et al., 1995). Whenever there is a phase shift between the timing of two variables, the correlation between the trunk flexion angle and the external moment would also be altered, reflecting the rate of postural changes. Such deviations may be due to the initial jerk (Danz and Ayoub, 1992) to overcome inertia, or to compensate for the perturbations of the center of gravity relative to the base of support. Exploration of these relationships may provide some insight into injury risk.

Insert Figure 1 about Here

One approach to exploring this relationship is the use of phase plane analysis. This technique has been used previously to explore joint coordination, such as the phase relationship between hip and knee joints (Burgess-Limerick, et al. 1993; Burgess-Limerick, et al. 1997; Burgess-Limerick, 2003) with critical implications on balance, joint loading and stability. Changes in the inter-joint coordination (e.g., from-proximal-to-distal, from-upper-to-lower extremities, or reversal sequences) could alter the timing and magnitude of the coordination between trunk flexion and moment about ankle, since

the trunk is in the middle of the kinetic chain (elbow-shoulder-hip-knee-ankle). The exploration of these relationships is the focus of the current study.

2 Data Source

Xu et al., (2007) conducted a study of lifting kinematics that compared the lifting technique of obese and normal weight participants. The first group was the normal weight participant group (BMI is less than 25kg/m²). The second group was the obese participant group (BMI greater than 30kg/m²). Twelve male volunteers from the university population participated in this experiment, with six participants in each group. These authors asked the participants to lift a load from the ground to a mid-chest location. Load weight (10% and 25% of lifting capacity) and asymmetry (0° and 45°) were varied across trials and there were 12 repetitions of each combination of the dependent variables. (Only those trials wherein the participants lifted the 10% load are considered in the current study.)

Trunk kinematics were captured using the Lumbar Motion Monitor (LMM, Chattanooga Group Inc., TN) (Marras et al., 1992) during the lifting tasks. This device was positioned along the length of the spine and is attached by a harness at the thorax and pelvis. The LMM captures trunk angular position in the three cardinal planes of human motion at a rate of 60 Hz. Angular velocities and accelerations are then obtained by differentiating the angular position as a function of time (Marras et al., 1992). To estimate the ankle moment, the ground reaction forces were collected by two force plates (Bertec Corporation, Model 4060A). The signals from the force plate were sampled at 60 Hz (details of these methods are provided in Xu et al, 2007).

3 Methods

Method 1. Phase Angle – Similar to Burgess-Limerick et al., (1993) kinematic analysis, one way to assess the coordination between trunk flexion angle and external moment is to calculate their relative phase angle. The phase angle is the argument on the phase plane, which is developed by plotting the time derivative of the variable against that variable. Figure 2 shows represents the phase plot of the sagittal trunk movement (top graph), in which α is the phase angle at a certain point in time, and the phase plot of the external moment in the sagittal plane (lower graph), in which β is the phase angle at the same time. To avoid extreme outliers and scaling effects in phase plot, all variables including the original measures and their time derivatives were normalized using z-scores. The magnitude of the relative phase angle (subtracting one phase angle from the other) represents the discrepancy of coordination between the kinematics variable (torso movement) and the kinetic variable (ground moment). Thus, the magnitude of relative phase angle at time t can be expressed as

$$\Delta\varphi(t) = \beta(t) - \alpha(t) = \tan^{-1}\left(\frac{\dot{M}_N(t)}{M_N(t)}\right) - \tan^{-1}\left(\frac{\dot{S}_N(t)}{S_N(t)}\right)$$

where M_N is the normalized moment, \dot{M}_N is the normalized derivative of the moment, S_N is the sagittal bend angle, and \dot{S}_N is the sagittal bend angular velocity

As suggested by Lindbeck et al. (Lindbeck and Kjellberg, 2001), maximum and minimum relative phase angle between the two phase plots could be used as the index to quantify the level of coordination. Based on the three marked points (one maximum bending angle position and two maximum velocity positions) in Figure 2, the phase angle of the trunk flexion is leading the phase angle of the external moment during almost the

entire lifting cycle. The phase shift was consistent with Toussaint et al. (1995) that the largest external moment to the center of gravity of body occurred during the concentric phase rather than the time of maximum trunk flexion. Figure 3 gives the profiles of the twelve participants' relative phase angle under symmetric / asymmetric lifting conditions.

Insert Figures 2 and 3 about Here

Method 2. Moving Correlation – During lifting without any perturbation if there is any direct responsive relationship between the kinematic and kinetic measurement, the correlation coefficient between the two variables should be quite high. Because the latency in human motor responding for errors in execution and selection is about 250 ms (Schmidt, 1988), the time window for calculating the correlation coefficient is adjusted to 250ms (15 successive points for 60 Hz sampling frequency) for capturing no more than one latency period. This method can be expressed as:

$$r_i = \frac{\left(\sum_{j=i}^{i+14} M_j S_j - \frac{\left(\sum_{j=i}^{i+14} M_j \right) \left(\sum_{j=i}^{i+14} S_j \right)}{n} \right)}{\left(\sum_{j=i}^{i+14} M_j^2 - \frac{\left(\sum_{j=i}^{i+14} M_j \right)^2}{n} \right) \left(\sum_{j=i}^{i+14} S_j^2 - \frac{\left(\sum_{j=i}^{i+14} S_j \right)^2}{n} \right)}; \quad i = 8, 9, \dots, n-7$$

where r_i is the correlation coefficient of the i th time window, M is the moment, S is sagittal bend angle, and n is the total number of point captured during one lift.

Each lift then yields a sequence of correlations (Figure 4). A zero correlation indicates that no apparent linear relationship between two variables. A high correlation implies that sagittal trunk flexion accounts for the external moment to a great extent

without any large acc-/deceleration of the limbs. Figure 5 gives the profile of twelve participants' moving correlation coefficient under symmetric / asymmetric lifting condition.

Insert Figures 4 and 5 about Here

4 Conclusions

The comparisons of the moving correlation and the phase angle shift are informative. It would be unusual to have a small phase shift (Method 1) corresponding to a small correlation (Method 2). In contrast, a large phase shift can cause disruption of profiles and reduces the correlation between the two measures. When a movement has fewer jerks (sudden change in acceleration or deceleration), the combination of small phase shift and large correlation reflects less complicated coordination. Finally large phase shift and small correlation represents a low coordination level. Thus, based on the aforementioned four possibilities, the quantification of the deviation from any given coordination provides information regarding the dynamics of postural changes during lifting tasks, which can be used to compare lifting patterns and to investigate the organization of body movement. Considering that obese people are more vulnerable in terms of workers' injury (Ostbye et al., 2007), these two methods may be also used to investigate differences in posture dynamics between normal weight people and obese people during various lifting tasks. When a lifting pattern has a large phase shift or a small correlation coefficient, it would be considered problematic since such lifting contains strong jerks, which require more muscle force and potentially cause injuries. Future study should quantitatively evaluate differences of phase shift and correlation

coefficient between normal weight people and obese people and that may help us unravel why obese individuals have higher morbidity.

References

- Burgess-Limerick R, Abernethy B, Neal RJ. 1993. Relative Phase Quantifies Interjoint Coordination. *Journal of Biomechanics* 26(1):91-94.
- Burgess-Limerick R, Abernethy B, Neal RJ, Kippers V. 1995. Self-Selected Manual Lifting Technique - Functional Consequences of the Interjoint Coordination. *Human Factors* 37(2):395-411.
- Burgess-Limerick R. 2003. Squat, stoop, or something in between? *International Journal of Industrial Ergonomics* 31(3):143-148.
- Chaffin DB. 1999. *Occupational Biomechanics* New York: Wiley-Interscience.
- Danz ME, Ayoub MM. 1992. The Effects of Speed, Frequency, and Load on Measured Hand Forces for a Floor to Knuckle Lifting Task. *Ergonomics* 35(7-8):833-843.
- Enoka RM. 1988. Load-Related and Skill-Related Changes in Segmental Contributions to a Weightlifting Movement. *Medicine and Science in Sports and Exercise* 20(2):178-187.
- Lindbeck L, Kjellberg K. 2001. Gender differences in lifting technique. *Ergonomics* 44(2):202-214.
- Marras WS, Fathallah FA, Miller RJ, Davis SW, Mirka GA. 1992. Accuracy of a three-dimensional lumbar motion monitor for recording dynamic trunk motion characteristics. *International Journal of Industrial Ergonomics* 9:75-87.
- Schmidt R. 1988. *Motor Control and Learning*. Champaign, Illinois.
- Toussaint HM, Commissaris D, Vandieen JH, Reijnen JS, Praet SFE, Beek PJ. 1995. Controlling the Ground Reaction Force During Lifting. *Journal of Motor Behavior* 27(3):225-234.
- Xu, X, GA Mirka, SM Hsiang (2007, In Press) "The Effects of Obesity on Lifting Performance", To Appear in *Applied Ergonomics*.

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Figure 3. Relative phase angle profile (ordinate, in degree) of twelve participants over symmetric and asymmetric lifting condition. The solid line is the average over twelve repetitions of lifting and the dash lines represent standard deviation. Data normalized in time to 100% of lifting cycle

Figure 4. Correlation coefficient sequence of one lift as the function of time

Figure 5. Moving correlation coefficient profile (ordinate) of twelve participants over symmetric and asymmetric lifting condition. The solid line is the average over twelve repetitions of lifting and the dash lines represent standard deviation. Data normalized in time to 100% of lifting cycle

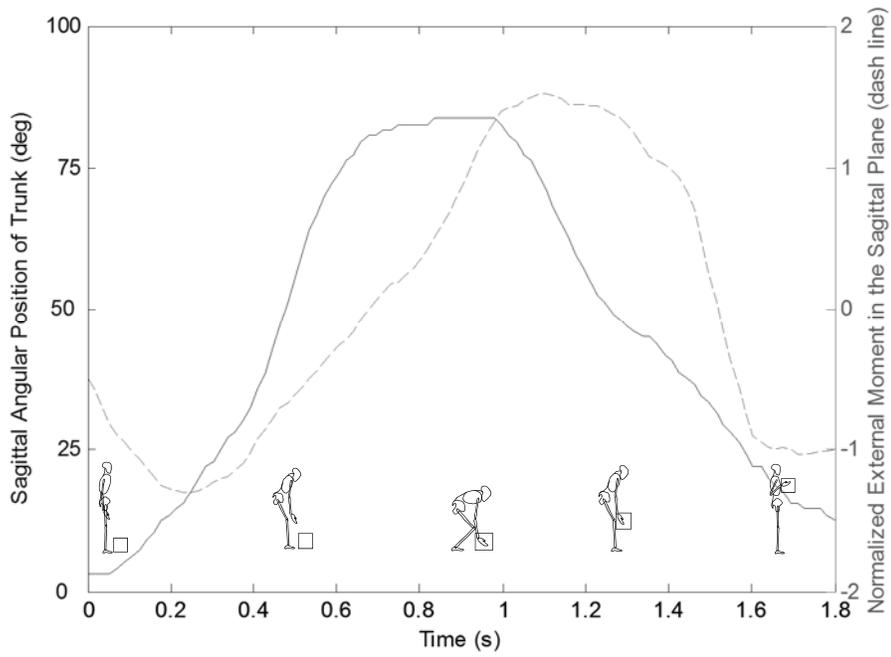


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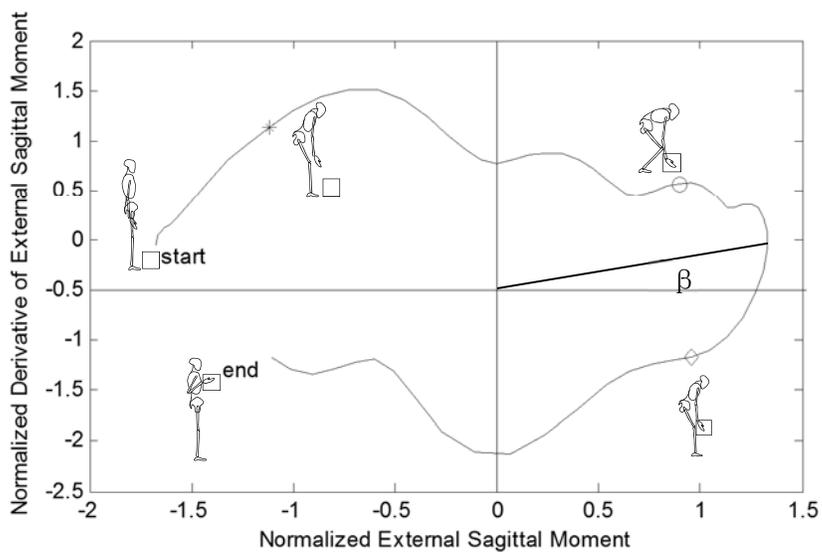
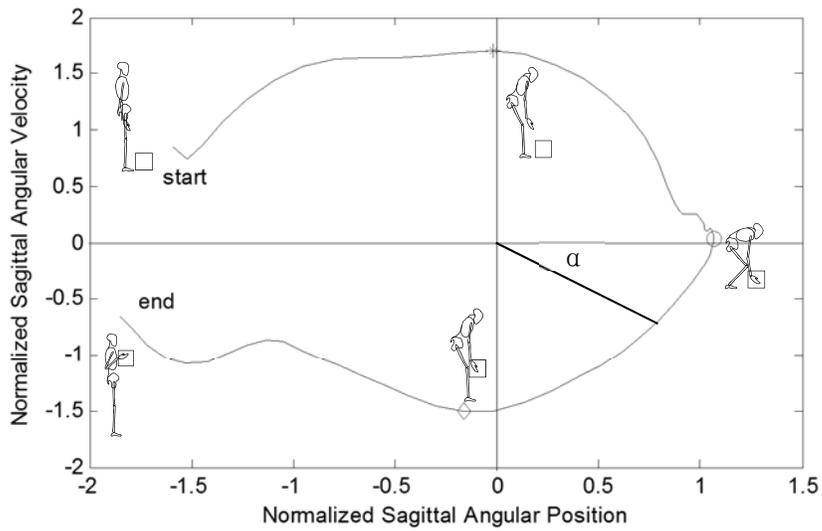


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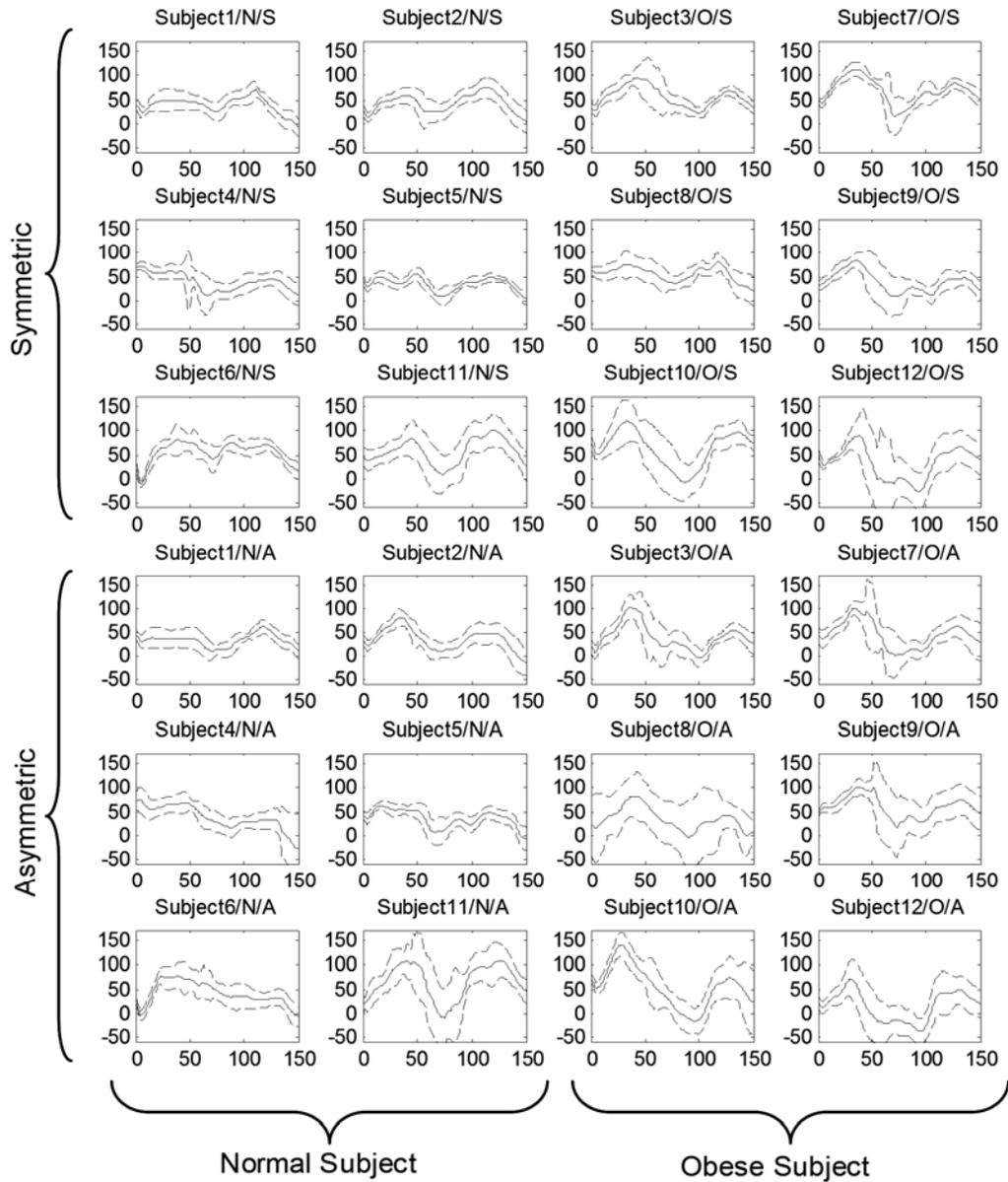


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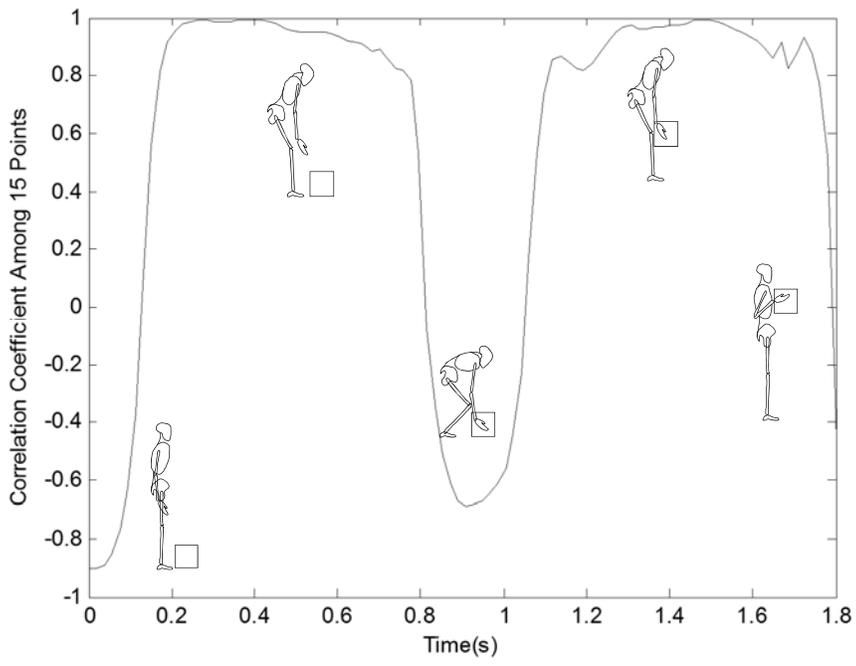


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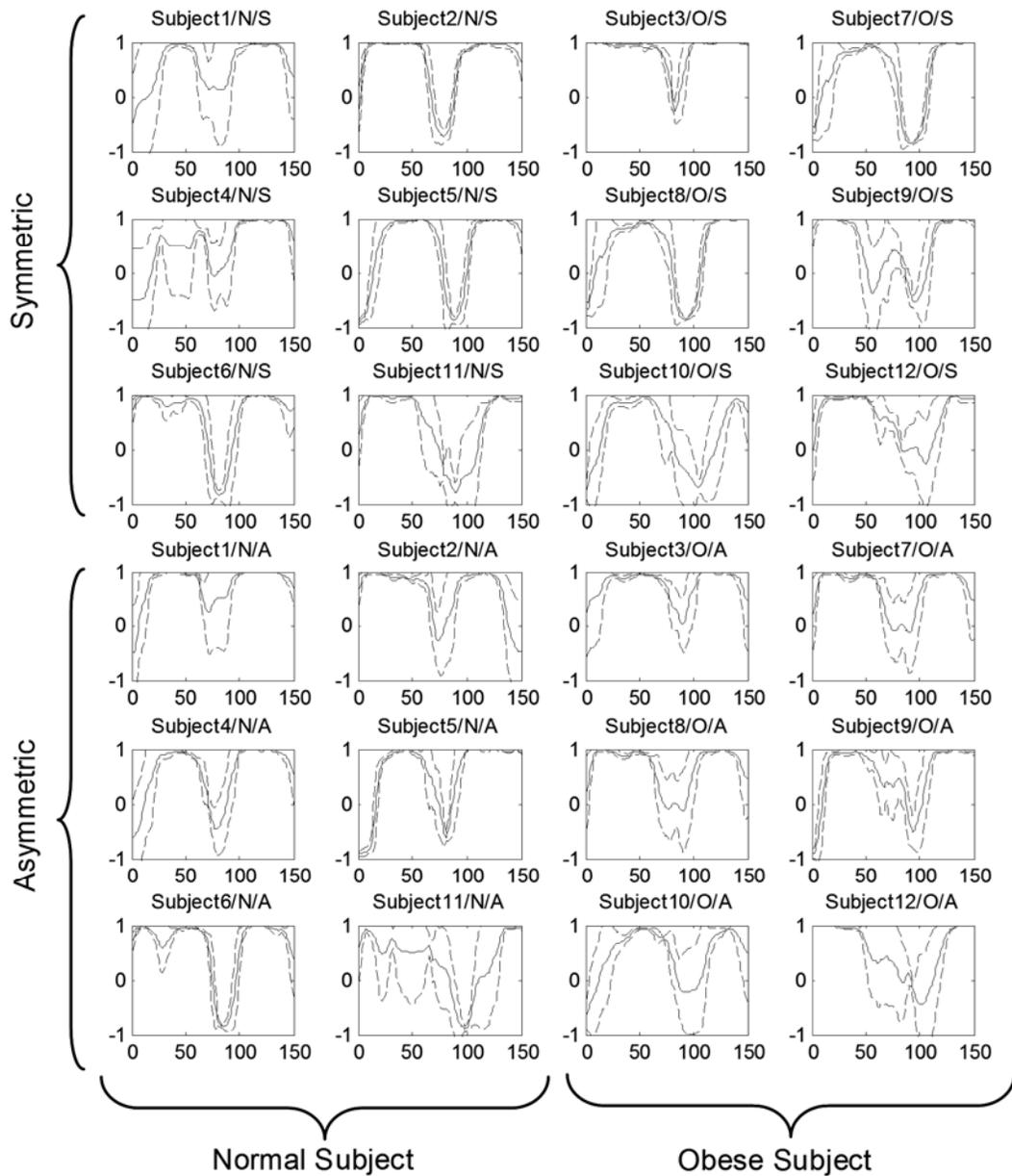


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