Novel use of retro-reflective paint to capture 3D kinematic gait data in non-human primates

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***Abstract*— Non-human primate models are extensively being used to study and understand biomechanical mechanisms of various neuro-motor pathological conditions such as Parkinson's disease. However, collecting full body 3D kinematics using current technologies for obtaining reliable objective biomechanical measures to precisely characterize gait mechanics in non-cooperating primates is laborious and daunting task. We developed a method to reduce data collection and analyses time by using retro-reflective paint, a mixture of reflective powder and petroleum jelly that was applied directly on the primate's skin. 3D kinematic data from three treadmill walking female rhesus primates (one normal and two MPTP treated) was collected using a four infrared camera system.**

Bilateral joint angle trajectories of hip, knee, ankle, shoulder and elbow for normal primate show 180 degrees out of phase. Step cycle duration and percentage stance are significantly different between the normal ($F(9,62)=128.2$) and MPTP ($F(9,62)=143.1$) treated primates. Step cycle duration between forelimb and hindlimb is not significantly different in all primates. However, percentage stance in less affected limbs of both MPTP treated primates is significantly higher in forelimb than hindlimb. Gait pattern of normal primate is diagonal symmetrical gait, one MPTP treated primate showed lateral symmetrical gait and other showed a non-standard gait pattern.

I. Introduction

Non-human primate (NHP) models are extensively being used to study and understand physiological and biomechanical mechanisms of various neuro-motor pathological conditions such as Parkinson's disease (PD). In advanced PD patients, it is reported that deep brain stimulation therapy relieves certain motor symptoms (tremor, rigidity) but the therapy becomes either ineffective or causes axial instabilities (akinesia, postural instability, and gait dysfunction) [1]. A major limitation in the studying axial instabilities of PD is the lack of techniques to objectively assess gait. A full body 3D kinematics similar to that of being performed in humans is essential to obtain reliable objective biomechanical measures that can precisely characterize gait mechanics. However, collecting full body 3D kinematics in usually non-cooperating NHP is a daunting and a challenging task. Current technologies use either active LED markers that are sewn into a customized garment [2], or passive retro-reflective markers that are placed directly on the skin of the NHP to collect kinematic data [3]. Donning of garment with active markers or placement of passive markers is challenging even when the NHP is restrained or is under anesthesia. Primary disadvantage associated with active marker technology is the slippage of the fabric on the skin at various joints introducing errors in the data. In passive marker technology, NHP picks the markers off the skin causing major disruption in data collection. Here, we have developed a method using retro-reflective paint as passive markers that can be applied directly on the skin surface to capture whole body 3D kinematics in primates.

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II. Methods

Data were collected from three female rhesus (Macacca mulatta) NHP. Normal (N), aged 14, is a non-MPTP treated NHP. M1, aged 9, was treated with right side intracarotid MPTP injections and had developed mild hemi-parkinsons symptoms. M2, aged 10, was treated with left-side intracarotid and systemic MPTP injections. M2 developed mild bradykinesia/akinesia on her left side and mild rigidity on her right side. The study was approved by the Cleveland Clinic IACUC. Retro-reflective paint was prepared by mixing reflective powder (3M^{TM} - 8010 Gray, 80% by Vol) and petroleum jelly (20% by Vol). A 1 mL syringe filled with paint was to apply the paint on the skin of the restrained primates. Before applying the paint on the bony landmarks of forelimbs, hindlimbs, metacarpo-phalangeal joint, and the outside tip of the third digit/finger, the bony landmarks were highlighted by black permanent marker to enhance the contrast of the passive marker and to increase repeatability of marker placement. Prior to data collection, calibration of 3D space was performed using a customized rectangular calibration cube. To further validate the system for accuracy during dynamic motion, a set square triangle with markers at the corners was moved back and forth in the calibrated volume to calculate dynamic angular and distance measurement errors. 3D kinematic data from left and right side were collected simultaneously from N using four-infrared video camera system (Peak Motus, CO) while walking at 1.5 miles/hour (0.675 meters/second) on a modified treadmill fitted with a custom-built treadmill enclosure. Data from less affected (LA) and more affected (MA) limbs of M1 and M2 were collected while walking at 0.8 miles/hour (0.36 meters/second) using two cameras in two separate sessions.

The markers were digitized offline and the digitized spatial co-ordinates were used to model body segments. Limb touch-down (TD) and lift-off (LO) events were marked when the primate's toe touched and lifted off from the treadmill

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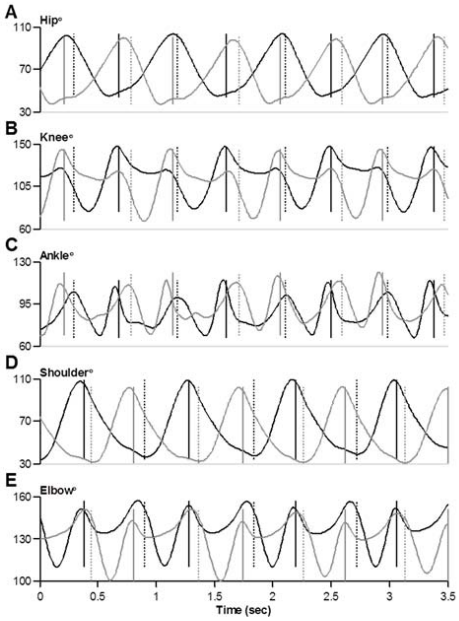

Figure 1: Angle trajectories (4 cycles) of hindlimb (right: black; left: grey) (A) hip, (B) knee and (C) ankle and, of forelimb (right: black; left: grey) (D) shoulder and (E) elbow along with lift-off (dotted vertical line) and touch-down (solid vertical line) event markers for the right hindlimb.

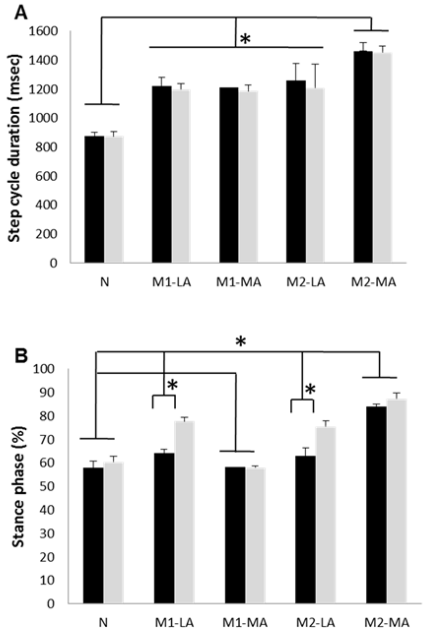

Figure 2: Average +SD values of (A) step cycle duration and (B) % stance phase within each cycle for hindlimb (black) and forelimb (grey) hip. Step cycle duration is not significantly different when compared between FL and HL in all NHPs. Percentage stance phase is significantly higher in FL when compared to HL in less affected limbs of M1 and M2. Step cycle duration is significantly lower in normal. Percentage stance phase is not significantly different when compared between normal and mild parkinsonian most affected side (M1-MA), but significantly higher in moderate parkinsonian NHP (M2) and in mild parkinsonian less affected side (M1-LA).

belt respectively. The swing durations (LO to TD), the stance durations (TD to LO), step cycle durations (TD to TD) and % stance phases were calculated on a cycle-by-cycle basis. A one-way ANOVA and Tukey-HSD post hoc were performed to compare the outcome measures. Values of $p < 0.05$ were considered significant.

III. Results

The dynamic angular and distance errors calculated from movements of a set square in the calibrated volume was less than 0.7 degrees and 0.35 cm and were within acceptable range. Joint angle trajectories from normal NHP are plotted in Fig. 1. Four gait cycles of hip, knee and ankle of hindlimb and, shoulder and elbow joint angle trajectories along with lift-off (dotted vertical line) and touch-down (solid vertical line) event markers are shown Fig. 1A-E. Angle trajectories from right (black lines) and from left (grey lines) are 180^0 out of phase (Fig. 1).

Step cycle duration and percent stance for each cycle for each limb from normal (N), M1 less affected (M1-LA), M1 more affected (M1-MA), M2 less affected (M2-LA) and M2 more affected (M2-MA) are presented in Fig. 2. Step cycle duration and percentage stance phases are significantly different between the groups with $F(9,62)=128.2$ and $F(9,62)=143.1$ respectively. Step cycle duration is not significantly different when compared between FL and HL in all NHPs. However, percentage stance phase is significantly higher in FL when compared to HL in less affected limbs of M1 and M2. Percentage stance phase was not significantly different when compared between N and M1-MA. However, the variation was found to be significantly higher in moderate parkinsonian NHP (M2) and in mild parkinsonian less affected side (M1-LA). Gait pattern of normal primate was diagonal symmetrical ($HL_R \rightarrow FL_L \rightarrow HL_L \rightarrow FL_R$); M1 was lateral symmetrical ($HL_R \rightarrow FL_R \rightarrow HL_L \rightarrow FL_L$) and M2 was a non-standard gait pattern ($HL_R \rightarrow FL_L \rightarrow FL_R \rightarrow HL_L$).

IV. Conclusion

We have successfully developed a method in which placement of markers was easier and enabled semiautomatic analyses of video data thus reducing data collection and analyses time for obtaining quantitative locomotor measures to characterize the gait in primates.

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