INVESTIGATING THE SEATED DOUBLE POLING CYCLE: IDENTIFYING BASELINE MEASURES FOR THE PREPARATION PHASE

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The purpose of this study was to identify baseline measures (BM) for the preparation phase (PREP) within the linear stroking cycle for the sport of sledge hockey. The addition of this phase to seated double poling is unclear biomechanically; full arm extension to pick-plant. A validated solid-static prototype mimicking the average single-armed adult male with dynamic shoulder joint was used to determine BM in 3 dimensions and initial pick-impact forces (GRF). Results indicated that average peak GRF occurred prior to 5.0×10^{-3}s post initial contact; F_y=179N, F_z=515N and F_x=573N. Evidence indicated PREP should initiate slightly below the horizon in order to produce the greatest non-contracting force for sledge propulsion. Isolated data provides insight to the biomechanics of the dynamic limb within PREP assisting with its importance to the complete cycle.

KEY WORDS: sledge hockey, stroking cycle, impact forces

INTRODUCTION: The shoulder joint's natural architecture produces the largest range of motion (RoM) within the human body; in order to achieve this RoM mechanical design warranted a reduction in the joint's structural integrity throughout 3-dimensions (Veeger & van der Helm, 2007). As a ball-and-socket joint this heightened level of *mobility* creates diminished confidence in the joint's ability to produce load-bearing *stability,* unlike the hip joint whose architectural design promotes structural compliancy through maximal load-bearing mobility (Veeger & van der Helm, 2007). Paralympic sledge hockey (male seated para-hockey) is a high-velocity high-impact sport dependent upon the shoulder joint's structural integrity in two ways: 1) the nature of the sport sanctions full body-contact were the shoulder joint, the most prominent exterior point of contact, is constrained to withstand and absorb the impact forces from an oncoming opponent 2) locomotion is produced solely from the shoulder joint in a double poling fashion where speed and quickness are dependent upon force-duration impact cycles. In addition to these simplified biomehanics of the sport, participants are commonly but not mandated to be considered within the shoulder-dependent daily-living special population (wheelchair or crutch-assisted). Therefore, trauma to the shoulder joint is inevitable for these athletes, however, scientific evidence can improve muscular training focuses, rehabilitation and provide advancement concerning sport-specific tasks.

Double poling has been investigated and determined to consist of two phases commonly known as: 1) *propulsion* the contact phase of the pole's pick with the terrain; pick-plant to pick-off, and 2) *recovery* the return phase of the cycle; no direct contact with the terrain (Holmberg et al., 2007). Seated double poling investigations suggest an additional third phase known as *preparation*; from full arm extension to pick-plant for a short pole length seen in such sports as sledge hockey and alpine sit-skiing or from pick-off to initiation of return to the forward cycle in sports such as cross country sit-skiing involving longer pole lengths (Lomond & Wiseman, 2003; Bernardi et al., 2013). The addition of this phase has been suggested due to observable changes within sledge movement and biomechanical parameter trends (Bernardi et al., 2013). However, the direct biomechanical benefit to the addition of this phase into the complete cycle is currently unknown warranting investigation.

This study investigated and determined baseline measures for preparation in the sport of sledge hockey using a validated anatomically correct solid-static average adult single-armed male prototype, where the shoulder joint was the only dynamic component; and a 3-dimensional motion capture system with force-plate. Obtaining baseline measures for external forces concerning the upper limb throughout this downward movement allows for comparison against internal forces either supporting or dismissing the assumptions required to be made when investigating dynamic movement. Baseline measures will also provide insight to the dynamic limb's contribution to the phase in turn the phase's overall importance to the complete cycle. The purpose of this study was to identify baseline measures for the preparation phase within the linear stroking cycle for the sport of sledge hockey.

METHODS: A previously validated methodology to investigate baseline measures for the preparation phase within the linear stroking cycle for the sport of sledge hockey was used. A solid-static prototype architecturally designed from US Marine Corp personnel data and previously determined parameters for segment shape, length and mass was built to represent a single armed average adult male weighing 80kg with dynamic shoulder joint. The prototype was used in conjunction with a Vicon motion capture system and Kistler force-plate to investigate the preparation phase of this forward stroking cycle; downward movement and contact force; data were collected at 200Hz and 800Hz respectively. The prototype was fastened to a sledge hockey sledge with fixed hip angle equaling 40^{o} from the horizon and weights placed in the bucket to off-set the balance allowing free stance. A velcro strap was attached to the forearm's centre-of-gravity (CoG) and raised to where the neck would be located testing shoulder start angles at +10^{o}, 0^{o} and -10^{o} from the horizon; then released allowing the arm to drop down and pick to contact the force plate. Two plastic washers 4.00cm in diameter were used to decrease friction at the dynamic joint. Two 1.30kg wrist-weights were attached to the upper arm in a stretched out fashion (lateral and medial) with an overlap at CoG mimicking arm morphology. A 1.20kg ankle-weight was attached to the lateral forearm in a stretched out fashion (Fig 1). Markers were placed at the joint-centre for the shoulder and elbow, upper arm CoG, forearm CoG, anterior wrist, posterior wrist, and blade, joint and pick of the stick. Additional markers were used to construct the torso and indicate the left superior anterior and posterior hip; markers were 14mm in diameter. Three useable trials investigating fixed joint angle combinations at the elbow 120^{o}, 135^{o} and 150^{o}, and wrist-stick at 45^{o} were acquired and processed using MATLab code for both trajectory and the force plate data; zero-lag fourth-order Butterworth lowpass filter at 12Hz and zero-lag second-order Butterworth highpass filter at 4Hz, respectively. Kinematic and kinetic data were collected and time-normalized allowing for comparison; pre contact to the initiation of stick recoil. A mathematical model was developed and used as a control for validation purposes.

RESULTS: Trajectory data illustrated similar curvature for all respective elbow angles showing an increase in arc-slope as the elbow angle decreased; similar to shortening the radius of a pendulum (Fig 2). On average the pick vertically displaced 0.55m, 0.52m, 0.60m for a 120^{o}, 135^{o} and 150^{o} elbow angle, respectively. Further investigation regarding elbow-pick-plant angle is currently being conducted. Point of rotation was also evaluated and labelled as a local origin; the shoulder (Fig 2). Results indicated that average peak impact reaction forces occurred prior to 5.0×10^{-3}s post initial contact and were 178.5N, 514.8N and 572.9N, mediolateral, vertical and horizontal respectively (Fig 3a). Reaction forces have a negative orientation within their respected illustrations to assist with a visual connection to an increasing force (more negative) from a downward motion. Again, as seen in the validation evidence horizontal reaction force on average was greatest producing 572.9N of reaction force onto the shoulder compared to 491.6N average vertical reaction force (Fig 3b); the mathematical model indicated that vertical reaction force was to be dominant. Average vertical reaction forces also indicated that the lower the start angle the greater the reaction force 273.7N, 553.9N and 716.9N for +10^{o}, 0^{o} and -10^{o}, respectfully (Fig 3b).

DISCUSSION: Baseline measures concerning external forces allows for comparison against the necessary assumptions made regarding internal forces within the human body during dynamic movement. Understanding baseline measures concerning the upper limb in this downward moving phase of the cycle will provide an evaluation tool used in subsequent research comparing musculoskeletal produced shoulder dependent locomotion in the sport of sledge hockey. Since the prototype had a fixed hip angle similarities or differences between baseline measures and musculoskeletal data isolated to the dynamic limb can be determined. This isolated data will provide insight to the biomechanics of the limb movement within the phase in turn its importance to the complete cycle. Additionally, further investigation concerning hip flexion-extension in conjunction with limb movement can be conducted; static torso trajectory compared to dynamic torso trajectory from musculoskeletal produced locomotion. From this baseline evidence preparation initiation should begin slightly below the horizon in order to produce the greatest non-contracting force to propel the sledge (Fig 3). Further investigation regarding pick-plant angle is currently being conducted to assist with understanding elbow flexion-extension throughout the phase; providing sport-specific evidence promoting maximal force transfer to produce sledge propulsion.
Combing this baseline data with musculoskeletal produced data a completed illustration of the linear stroking cycle will be created outlining phase duration, muscular contributions within each phase, parameter biomechanical trends, and key components such as peak impact forces, peak reaction forces, pick-plant and pick-off. The cumulative goal for this research is to provide a definition for shoulder produced gait similar to that which currently exists for hip produced gait. In turn a sport in much need of scientific evidence will gain a completed understanding of how locomotion is produced and how to enhance athletic performance. Additionally upon completion, this research will provide shoulder-dependent daily-living populations a heightened understanding of shoulder produced gait allowing for advancement in muscular training and rehabilitation. Shoulder produced gait occurs in a forward cyclical motion similar to the linear stroking cycle see in sports such as sledge hockey; wheelchair propulsion and crutch assist locomotion. Understanding weight-bearing shoulder produced gait will reduce the risk of overloading this highly mobile joint in turn reinforcing structural integrity.

CONCLUSION: In conclusion this study has determined baseline measures for the preparation phase within the linear stroking cycle seen within the sport of sledge hockey. These baseline measures will be combined with musculoskeletal data in order to determine the biomechanical importance of preparation to the complete cycle. This evidence will be combined and illustrated from static-start to momentum driven cycles providing sledge hockey advancement in a necessary but basic skillset; the linear stroking cycle.

Figure 1: Illustration of the validated solid-static prototype used to determine baseline measures for the preparation phase within the sport of sledge hockey (not test position).

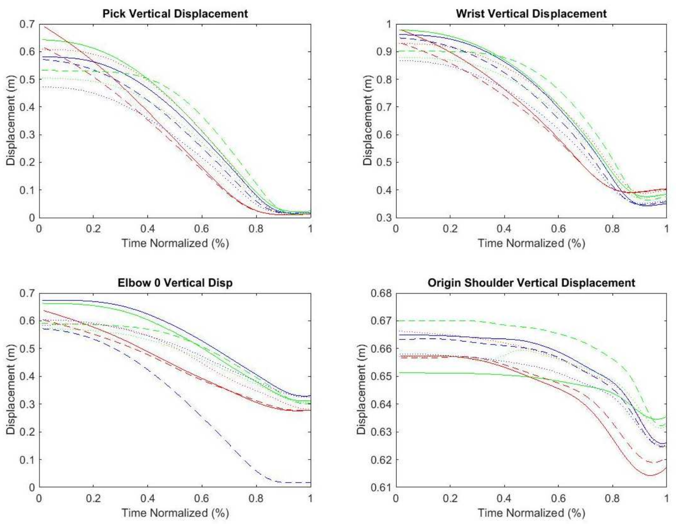

Figure 2: Average vertical marker trajectories for the pick, wrist and elbow during all trials. The shoulder origin is provided for reference. Blue 150°; Green 135°; Red 120° elbow angles; line +10°; --- 0°; … -10° start angles.

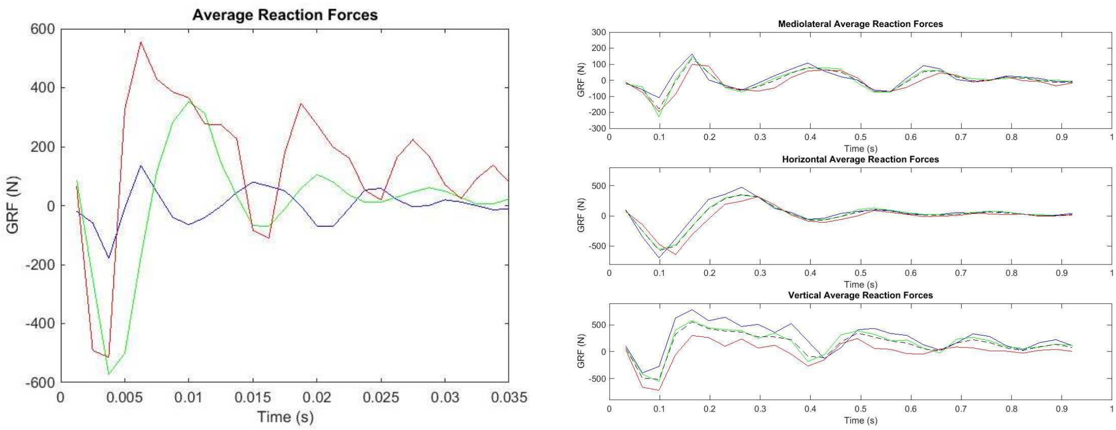

Figure 3a: Average vertical reaction forces from initial pick-impact. Blue Mediolateral; Green Horizontal; Red Vertical. 3b: Average reaction forces from initial pick-plant time-normalized. Blue +10°; Green 0°; Red -10° start angles; Black --- average.

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