APPPLYING STATISTICAL PROCESS CONTROL TO IDENTIFY TRANSITIONARY FOOT MOTIONS DURING MANUAL MATERIAL HANDLING TRANSFER TASKS

David W. Wagner and Matthew P. Reed
University of Michigan, Ann Arbor, MI, USA
E-mail: dwwagner@umich.edu Web: www.humosim.org

INTRODUCTION

The transition between cyclical gait and non-cyclical stepping has been well studied during the initiation and termination phases of the gait cycle (Breniere, and Do, 1991; Nissan and Whittle 1990). Progression velocity and step frequency during the initiation, rhythmic, and termination phases of gait have been used to establish the step at which a transition to or from nominal gait occurs (Sparrow and Tirosh, 2005). Research has not focused on the similar transitions in stepping behavior during manual material handling (MMH) tasks.

Statistical process control (SPC) is traditionally associated with monitoring a manufacturing process for unusual causes of variation (i.e. equipment malfunction). A control chart, a primary technique of SPC, is a method for identifying a deviation in the process from a sample of parts produced by the process (Montgomery et al. 2001). A method for applying a Shewhart control chart to monitor stride velocity during a MMH pickup transfer task and identify at which step a deviation from nominal gait occurs is presented.

METHODS

Whole-body motion data were gathered with a six-camera Qualisys Proreflex 240-MCU optical based motion tracking system sampled at 50 Hz in the Human Motion Simulation (HUMOSIM) laboratory at the University of Michigan. Ground contact times for each heel and toe were captured at 500 Hz with footswitch signals. Participants were instructed to move a load with two hands between two shelves with a 45-degree delivery angle (Figure 1). Shelf height was scaled to 0.53 times participant stature. Data were obtained from 7 male and 8 female participants between the ages of 20 and 30. The protocol was approved by an institutional review board and all subjects provided written, informed consent.

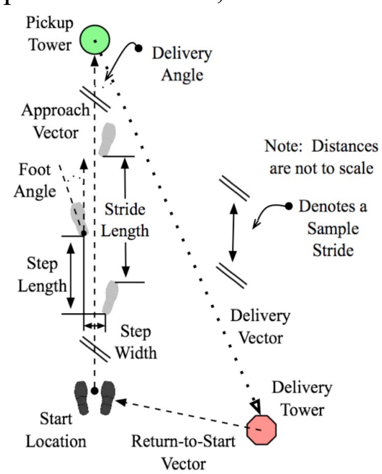

Figure 1: Schematic of MMH transfer task and selected spatial gait parameters.

Spatiotemporal parameters of step length, stride length, step width, foot angle, instantaneous velocity of progression, and step frequency were computed for each trial (Figure 1). The gait parameters for a nominal stride were calculated for each trial between the first and third heel contact step events after the trial began (Brienere and Do, 1991). Results for stride velocity are presented here. Stride velocity is defined as the stride length divided by the elapsed time between consecutive ipsilateral heel strikes.

A Shewhart chart was constructed for monitoring instantaneous stride velocity at each step throughout a trial. The center line (CL) was calculated as the average nominal gait stride velocity across trials for each participant. Upper and lower control limits (UCL and LCL) were calculated as the CL +/- 3σ respectively, where σ is defined from published intra-subject coefficient of variation (CV) values (Beauchet et al., 2005). The transition from the nominal gait cycle is defined when stride velocity for a particular step is outside the range defined by the LCL and UCL.

RESULTS AND DISCUSSION

Descriptive statistics for stride length and stride velocity (mean +/- standard deviation) are presented for all the observed trials. The stride length (137.4 +/- 13.6 cm) and stride velocity (118.5 +/- 12.6 cm/s) were computed for fifteen participants and are consistent with the nominal values published by Beauchet et al, 2005.

A representative control chart for the stride velocity of one trial (subject 10) is presented (Figure 2). Steps 1 and 2 are initialized from the stationary posture. Nominal gait stride velocity is reached by the 5th step and consistent with nominal gait until the step after the load is lifted. Trials were excluded if the stride velocity for a nominal gait cycle was not achieved. Thirty-one trials were analyzed. In 77% (90%) of the trials once a nominal gait velocity was achieved, it was maintained until the step (two steps) prior to when load pickup occurred.

The use of statistical quality control as a measure for defining the transition between cyclical gait and non-gait stepping behaviors has shown promise. However, knowledge of nominal means and variances of gait parameters are crucial to defining accurate control charts. A limitation of the work presented here is that population CVs were used to define the control limits. The use of subject specific variations would improve transition detection by increasing the sensitivity of the control charts over the ones presented here. Identifying transitions between nominal gait and other stepping behaviors during gait initiation, gait termination, turning, stepping over obstacles, and climbing stairs are just a few of the possible applications of this approach.

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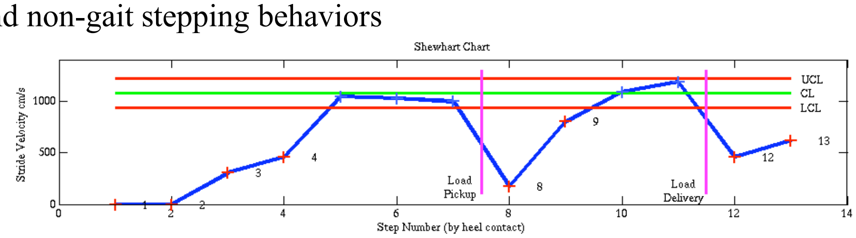

Figure 2: Representative Shewhart control chart of stride velocity for a single trial.