Sensitivity of toe clearance to leg joint angles during extensive practice of obstacle crossing: Effects of vision and task goal

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During obstacle crossing, a minimal vertical distance between swing foot and obstacle top (toe clearance) has to be preserved to avoid tripping and falling (Patla, 1997). A methodology to determine the sensitivity of toe clearance to swing leg joint angles during gait has been proposed by Moosabhooy and Gard (2006). High sensitivity means that smaller joint angle changes would generate larger changes in the toe clearance. Thus, the sensitivity joint profiles should reflect the strategy to obtain a desired toe clearance, a critical aspect of locomotion control usually dependent on visual information, when available. The main purpose of the present study was to analyze the effects of unavailability of visual information and task goals on the sensitivity of toe clearance to leg joint angles during extensive practice of the obstacle crossing task. Goals of accuracy and velocity were explored to avoid variability possibly associated with the choice of step velocity

Method

Twenty-eight young adults with normal vision were equally divided in four groups: two blindfolded groups had task goals defined as accuracy (A) and velocity (V); the other two groups (AC and VC) were their respective controls, with vision available. Participants walked with bare feet along a five meter flat pathway with an obstacle of 26 cm height located at 3 m from the starting point. Each participant performed 1,000 trials of the obstacle crossing task; the first trial and one every 50 trials were video recorded (60 Hz) for kinematical analysis. Motion data were filtered with fourth order Butterworth filter (cut-off frequency of 4 Hz) and used to obtain the dependent variables (Figure 1):
critical time, toe peak time, toe-obstacle distance, obstacle-heel distance, toe clearance, toe clearance sensitivity to hip, knee, and ankle angles (TCS$_H$, TCS$_K$, and TCS$_A$, respectively), step velocity, and error. Data from each dependent variable were submitted to a group by trials ANOVA, with repeated measures in the last factor. The significance level adopted was 0.05.

Results and Discussion

This study analyzed the effects of unavailability of visual information and task goals of accuracy and velocity on the sensitivity of toe clearance to leg joint angles during extensive practice of the obstacle crossing task. Unavailability of vision during the test was expected to change the locomotion pattern while motor experience increases via repetition. Additionally, the manipulation of task goals could clarify for obstacle crossing the effects of the well-known speed-accuracy trade-off as opposed to a self-selected gait speed situation. The sensitivity analysis was used to identify eventual joint angles strategies to accommodate motor adjustments related to practice and the absence of vision.
Figure 2. Mean (±SD) toe clearance sensitivity (cm/rad) to hip, knee, and ankle as a function of time (%) of accuracy (top left), velocity (top right), accuracy control (bottom left), and velocity control (bottom right) groups. The dashed vertical lines indicate the critical time.
Unavailability of visual information resulted in larger toe clearance only in the first trials and disappeared as practice continued; during initial trials, vision availability increased toe-obstacle distance for both task goals. Higher number of crossing errors was observed for the experimental groups. Increased sensitivity values for hip and knee joints occurred at critical time; critical time was not affected by task goal or practice. Toe peak time occurred clearly earlier than critical time, but was modulated by both task goal and practice. Surprisingly, results demonstrated that an extensive amount of practice was not capable of altering the toe clearance and its sensitivity to swing leg joint angle and critical time during obstacle crossing. However, practice changed step velocity and the amount of errors.

This experiment presented evidence that there are strong regularities in the kinematical profiles of the swing leg during obstacle crossing that are not dependent of practice. One thousand trials of practice did not change consistently critical time, toe clearance, and toe clearance sensitivities to hip, knee, and ankle rotations. The order of relative importance of leg joint rotations (hip, knee, and ankle), the moment of peak of sensitivities close to critical time, and critical time itself were maintained throughout trials. Effects of group seemed to show that both the unavailability of vision and the increase of velocity have similar effect, reducing the magnitude of the sensitivity of hip and knee to toe clearance at critical time. The results are in agreement with the notion of trade between safety and efficiency in locomotor control (Sparrow & Newell, 1994; Sparrow et al., 1996). The situations of higher risk such as crossing an obstacle without vision available or in a faster manner require a strategy in which toe clearance is more sensitive to the motion of more proximal leg joints (hip and knee), generating rotations with larger modifications of foot positions and possibly avoiding tripping and falling (Forner Cordero, Koopman & van der Helm, 2003); such interpretation needs further investigation.

References


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