Newly Walking Toddlers: How Do Different Strategies Combine When Developing Pendulum Mechanism?

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Abstract— **During the first months of independent walking toddlers use different gait strategies and then converge to more similar walking forms, developing manifestation of the pendulum mechanism. The extreme modes of walking usually adopted by toddlers are three: the Twister, the Faller and the Stepper. The aim of this work was to analyze quantitatively how toddlers explore those strategies and combine them when developing the pendulum mechanism.**

Twenty healthy infants participated in the study. Each infant performed 5 tests in 6 months after the onset of walking. Two tri-axial wireless inertial sensors were mounted respectively on the lower back and on the right leg. The participants were asked to freely walk in the room. For all the participants 10 consecutive strides were analyzed. A typical parameterized waveform was designed for each gait strategy. Each waveform was fitted into toddler data and then subtracted from the signals. Percentage of residual signal power was calculated as an indicator of how much the gait deviated from the intended strategy.

Preliminary results of signal power analysis are based on three toddlers, each one showing at the first week of independent walking a different gait strategy. Each toddler explored and combined mostly two of the three strategies presented when developing the pendulum mechanism. The two combinations found were twister and faller or stepper and twister: faller and stepper strategies appeared to be alternative in the development of mature gait. The analysis of more data will confirm this first conclusion.

Keywords— ***Toddlers, gait strategies, pendulum mechanism.***

I. INTRODUCTION

Many studies have analyzed infants at the onset of independent walking in order to evaluate the development of different strategies and coordination [1, 2]. In particular, Mc Collum et al [3] described qualitatively the mechanical strategies that toddlers use during the first few weeks of independent locomotion. Three basic forms of walking were presented:

- the Twister, who dominantly exploits trunk twist (Fig.1a) for progression;

- the Faller, who dominantly exploits gravity for progression (Fig.1b);

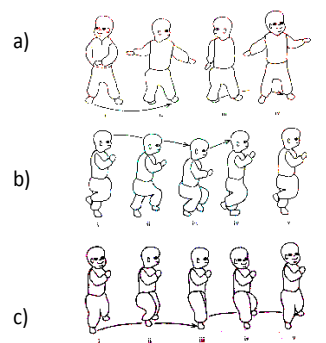- the Stepper, who dominantly controls the balance of the center of mass during progression (Fig.1c).

Fig. 1 Walking forms [3]: (a) twister, (b) faller, (c) stepper.

Toddlers use a mixture of these mechanical strategies during the first weeks of walking experience and then converge to more similar walking forms over the first few months of independent locomotion, when also they begin to develop and show some manifestation of the pendulum mechanism.

It could be argued that the pendulum mechanism is the result of the superimposition of the three basic walking forms: this assumption could be confirmed analyzing objectively biomechanical data of toddlers during their first months of independent walking.

In this work, longitudinal gait data were collected on toddlers from the onset of independent walking for six months using wireless inertial sensors (inertial sensors were useful as they can be worn under the clothes facilitating the experiments with infants). Data were used to quantitatively observe and analyze the mechanical strategies used by toddlers and analyze how those strategies develop into the pendulum mechanism.

The aims of this work were:

- to identify the major characteristics of toddler gait strategies using inertial sensors;

- to evaluate data collected on toddlers during their first months of walking and quantify objectively

how the gait strategies change towards a pendulum mechanism;

- to preliminary verify the hypothesis that the pendulum mechanism results with the composition of the three presented gait strategies.

II. MATERIALS AND METHODS

Twenty healthy infants (77±3cm, 10±2kg, 13±2months) were included in the study. All of the infants were full-term at birth and had no known developmental delays. Tests on the infants were scheduled once a month after the onset of independent walking for three months (T1, T2, T3) and one after six months (T6). When possible, a test during the very first week of independent walking was performed (T0) (twelve infants). Two tri-axial wireless inertial sensors (OPALS, Apdm, USA) were mounted respectively on the lower back and on the right leg. The participants were asked to freely walk in the room. For all the participants 10 consecutive strides were analyzed. Right heel strike (HS) and toe off (TO) instants were estimated from the angular velocity of the lower limb [4].

First, gait strategies used at the first week of independent walking were identified both visually during the test and from the trends of accelerations and angular velocities. Based on the theoretical description presented by McCollum et al [3] the following characteristics have been searched for in the data:

- Twister strategy was expected to show a high angular velocity around L5 vertical axis;
- Faller strategy was expected to show a high peak to peak L5 acceleration range along the AP axis;
- Stepper was expected to show low peak to peak range at L5 acceleration and angular velocities in all directions. The rapid movements of the foot were expected to show high accelerations of the legs happening in a small percentage of the stride.

Data at T0 were grouped for strategy and a typical parameterized waveform, reproducing the characteristics described above, was designed for each one.

Each waveform was fitted into toddler data and then subtracted from the signals. Percentage of signal power left was calculated as an indication of how much the gait deviated from the intended strategy.

III. RESULTS

The identified waveforms representative of the principal toddler gait strategies were:

- Twister: a sinusoidal function on the angular velocity around the vertical axis of L5 (Fig.2a)

$$Asin(Bx + C) + D \qquad (1)$$

- Faller: an inverted saw-tooth waveform on the antero-posterior acceleration of L5 (Fig.2b)

$$A * \left(-\frac{t}{B} + round\left(\frac{t}{B} + \frac{1}{2}\right) \right) + C \qquad (2)$$

- Stepper: a sinusoidal function on the vertical acceleration of the foot for 20% of the stride and then a constant value (Fig.2c).
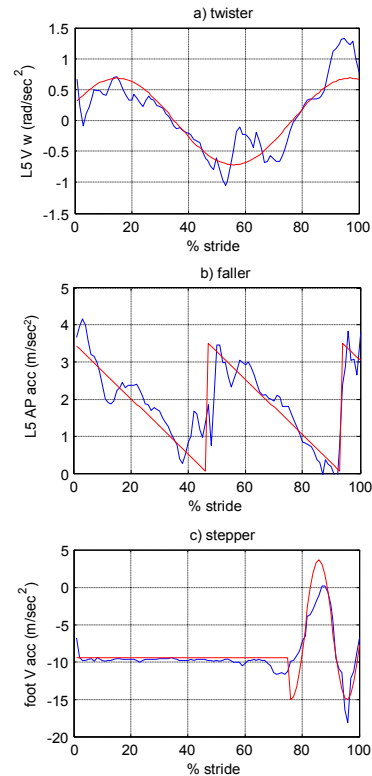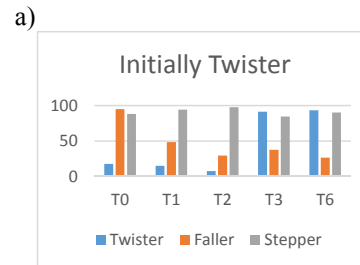
Fig. 2 Measured signal (blue) and estimated waveform (red) for (a) twister, (b) faller, (c) stepper.

Preliminary results of signal power analysis are shown in Figure 3a, 3b and 3c for three toddlers, each one showing at T0 a different gait strategy.
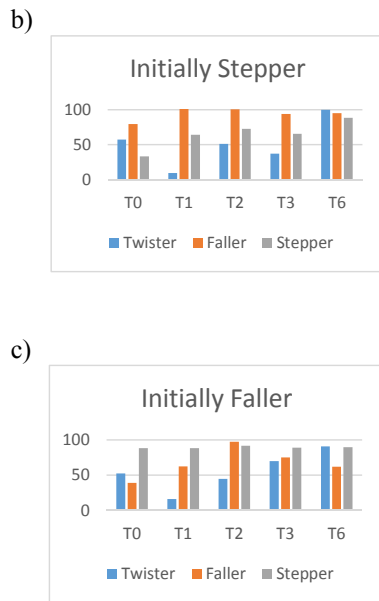
a)

b)

Initially Stepper

c)

Initially Faller

Fig. 3 Percentage of signal power left after removing the estimated trend of each gait strategies (twister in blue, faller in orange and stepper in grey) at different stage of gait development. Figures show results of 3 toddlers who manifested during the first week a twister (a), faller (b), stepper (c) strategy.

Assuming that the percentage of signal residual power indicates of how much the gait deviated from the intended strategy, the "initially stepper" toddler used the twister strategy from T0 to T2 and then left it, while from T1 to T6 explored also the faller strategy. Stepper strategy was almost not used.

The "initially faller" toddler used the faller strategy less and less from T0 to T2 and the twister strategy from T1 to T3. Stepper strategy was not used.

The "initially stepper" toddler explored at first the stepper strategy and then the twister one (from T1). Faller strategy was not used.

The major characteristics of pendulum mechanism [5] appeared in most of the toddlers data at T1 and became more and more evident from T1 to T6.

IV. Discussion

In this work gait strategies used by toddlers were investigated using inertial sensors. Three different waveforms, characteristics of different toddler strategies were identified. Preliminary results showed that each toddler explored and combined mostly two of the three strategies presented when developing the pendulum mechanism. The two combinations found were twister and faller or stepper and twister: faller and stepper strategies appeared to be alternative in the development of mature gait.

The analysis of more data would confirm this first conclusion. Further work is needed to understand how the different strategies combine in order to create the pendulum mechanism.

V. Conclusions

The present work showed how inertial sensors can be useful for analyzing in a quantitative way different gait strategies in newly walking toddlers. Preliminary results showed that each toddler explored and combined mostly two of the three strategies presented when developing the pendulum mechanism: faller and stepper strategies appeared to be alternative in the development of mature gait. The major characteristics of pendulum mechanism appeared in most of the toddlers data after one month of walking experience. Further work is needed to understand how the different strategies combine in order to create the pendulum mechanism.

VI. Conflict of Interest

The authors declare that they have no conflict of interest.

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