Assessment of changes in movement complexity and movement automaticity with maturation

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***Abstract*— The present work aims at testing multiscale entropy (MSE) on trunk acceleration data to assess movement complexity and its changes with maturation. If MSE can measure movement complexity, it should decrease with maturation in paradigmatic tasks (e.g. gait), because of the concurrent increase in automaticity, and increase in non-paradigmatic tasks (e.g. tandem gait). Children, adolescents, and adults participated in the study. MSE was estimated on trunk acceleration data during gait and tandem gait. Results agreed with the hypothesis, indicating MSE as a complexity measure sensible to differences in performance related to age and level of automaticity, specific of the performed task.**

***Keywords*—Motor control development, Movement complexity, Inertial sensors, Sample Entropy**

I. Introduction

MOTOR development beyond infancy is characterized by a gradual increase in agility, adaptability, and ability to make complex movement sequences [1]. Complexity of movement can be defined as the capability of using different strategies (complex strategies) to accomplish a specific task [2]. It can be described by the regularity of the pattern of variability and by the number of strategies used over time [2], and it is assumed to increase with increasing interactions among multiple control mechanisms operating over a range of time scales, reflecting system's capacity to adapt to environmental stresses. Thus, it is expected to increase with maturation, reaching its highest level in adulthood [3].

Multiscale Entropy (MSE) has been proposed to estimate complexity (assessed by sample entropy, SEN) on different kinematic signals, at different time scales (using different values of τ) [4]. When applied on trunk acceleration data during natural gait (NW) at different ages, MSE was found to decrease from childhood to adulthood, apparently contradicting the premises [5]. On the contrary, authors hypothesized that this decrease was related to the specific motor task analyzed and resulted from the concurrent increase in gait automaticity [5].

This work aims to test this hypothesis, applying MSE on a non-paradigmatic task (tandem gait, TW) in order to exclude aspects of automaticity: if MSE allows estimating movement complexity, an increase with maturation is expected in TW performance.

II. Materials and Methods

A. Study subjects

Seven groups of participants of different ages were included in the study: children aged 6-10 years (6YC, 7YC, 8YC, 9YC, 10YC), adolescents (15YA) and young adults (25YA).

All of the children had no known developmental delay. All children and adults had no musculoskeletal pathology and had a BMI between the 5th and the 95th percentile of the BMI-for-age [6]. None of them had previous experience of TW.

B. Experimental setup

Two tri-axial wireless inertial sensors (OPALS, Apdm, USA) were mounted respectively on the lower back and on the right leg using straps. Data were recorded at 128Hz while the participants walked in NW and walked in TW at self-selected speed back and forth on a 10m long tapeline on the floor.

C. Data Analysis

Stride detection was estimated from the angular velocity around the medio-lateral axis of the leg [7]. For both NW and TW, the turns, the first two and the last two strides of each trial were excluded. For all participants 10 consecutive strides were analyzed. Each time series included a number of data points higher than 3000 [4], [8].

SEN was calculated according to Bisi & Stagni 2016 [5] on the V, AP and ML accelerations of the trunk (SENv, SENap and SENml) for NW and TW (τ ranging from 1 to 6).

In order to evaluate the concurrent development of automaticity and complexity, each SEN value in NW was expressed in percentage of the corresponding value in TW (for each value of τ) to represent the ratio (R-SEN).

A Jarque-Bera test [9] was performed to test normal distributions of the estimated parameters on the different groups: since the normal distribution was not verified on all the groups, median values and 25- and 75- percentiles of results were calculated. A Kruskal-Wallis test [10], [11] with minimum level of significance of 5% was performed to analyze the effect of age on SEN and R-SEN.

III. Results

TW SEN followed the trend hypothesized with maturation on all the three axes, showing median values increasing significantly with increasing group age. NW SENap and SENv decreased significantly with age (SENap when using $\tau>4$), while no age effect was found on ML axis.

Significant age effect was found for R-SEN in all directions for all τ. Similar value trends were observed for this parameter for all τ in the different directions: R-SEN is 100% (AP) and 85% (V) in 6YC decreasing to 50% at maturation; 115% in 6YC decreasing to 90% for ML direction. Fig. 1a, b and c show respectively results for SEN in TW, in NW and R-SEN for the AP and V (τ ranging from 1 to 6).

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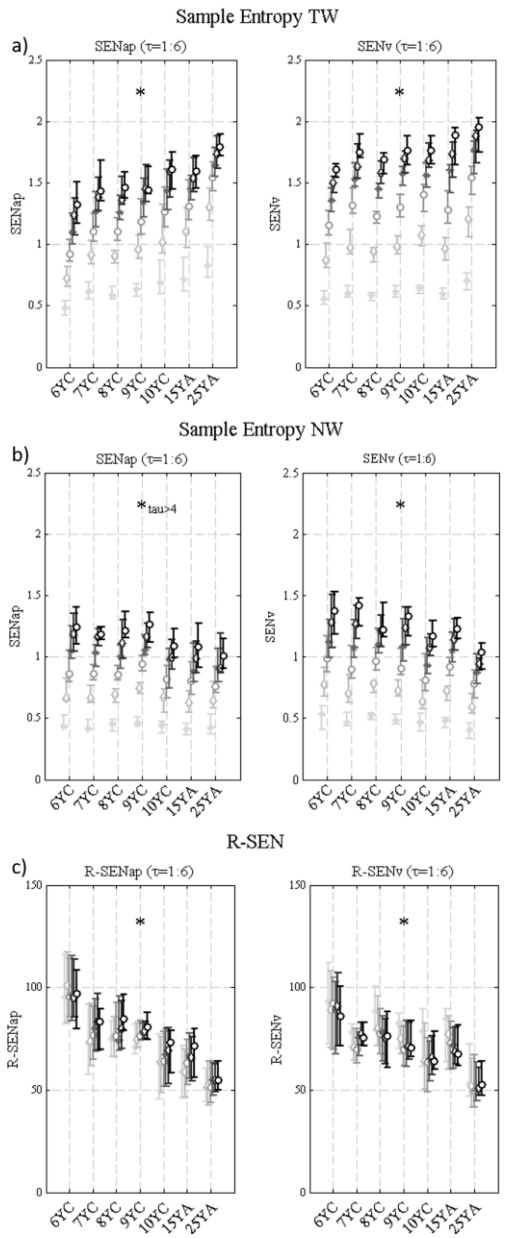

Fig. 1. a) SEN in TW, b) SEN in NW and c) R-SEN (%) for the different age groups (median, 25th and 75th percentiles), obtained with different values of τ (τ =1÷6 from light grey to black). Asterisks indicate significant age effect.

IV. Discussion

The results of this study confirmed the expected trend: age of maturation affected significantly complexity of the acceleration signal in all the directions, particularly in AP and ML that are stressed during TW by the constricted base of support, thus possibly evidencing adaptive/complex solutions found by motor control. Differently from what was observed for NW here and in previous research [5], SEN calculated for TW allowed to detect the expected increase in the complexity of motor control for all τ.

In particular, the ratio R-SEN between the two walking conditions can provide an insight into the concurrent maturation of motor automaticity. Assuming the development of complexity in TW as reference, R-SEN in NW shows a reduction to half of the complexity of TW for all time-scales in AP and V directions (in the plane of pendulum behavior [12]), while remaining comparable in the ML direction.

The results of the present study showed MSE and R-SEN, applied to NW and TW, capable to detect the expected changes in motor control maturation, taking into account the concurrent development of automaticity and complexity. This work highlights the importance of the selected task when aiming to analyze the different aspects of the maturation of motor control.

V. Conclusion

The results of this study confirmed MSE, estimated on trunk acceleration data, as a characterizing parameter of the maturation of motor control, sensitive to age related changes in both motor automaticity and complexity.

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