Frequency content of gait trunk acceleration: a longitudinal study

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***Abstract*— Acquisition and elaboration of trunk acceleration signal during gait have assumed a key role in motor assessment. This has led to develop different indexes and metrics to evaluate gait performance that, directly or indirectly, imply the analysis of the harmonic content of the signal. In addition, smartphones with embedded accelerometers have been proposed as a monitoring tool, even when not supporting high sampling frequencies. Thus, the knowledge of the spectrum characteristics of the trunk acceleration signal during gait is crucial to identify hardware and software requirements and to correctly use the indexes and their parameters. The aim of the present study was to analyze the harmonic content of the trunk acceleration signal characterizing the gait of nine age groups from 7 to 85 year-old. To do this, the fundamental frequency and the frequency corresponding to the 50, 90, 95 and 98% of the normalized power of the trunk acceleration during gait were analysed. Results highlighted that: the harmonic content (at 98%) of the acceleration signal for all the analysed population, with exception of the adolescents, is below 30 Hz where the high frequencies contribute is due to the AP direction. Regarding the adolescents their spectrum is wide up to 45Hz.**

***Keywords*— Gait frequency analysis, stride frequency, fundamental frequency, gait signal bandwidth.**

I. INTRODUCTION

NOW a day, the accelerometer measures during gait are extensively used to evaluate motor functionality of both healthy and pathological subjects [1], [2]. In particular, trunk acceleration during gait permits to characterize different aspects of the motor pattern itself. [3]. Moreover, a variety of metrics and indexes to evaluate variability, stability, complexity and regularity of the gait motor pattern have been developed [4]–[6]. Some of these indexes directly or indirectly analyse the harmonic content of the employed signal. Even if literature [5], [7], [8], referred to significant changes in gait pattern in relationship with the analysed population, assessed through direct or indirect analysis of the harmonic content of the signal, but, the lack of a standardize procedure for the signal acquisition (e.g. sampling frequency, time duration of the signal) clearly appears. Moreover, other works through using smartphone embedded accelerometers, which do not support constant and higher than 50 Hz sampling frequency due to the multiple functions they provide, analysed variability and stability aspects of gait in pathological populations [9]. Thus, the knowledge of the spectrum features (e.g. fundamental frequency, bandwidth) of the trunk acceleration signal during gait is crucial (i) to identify hardware and/or software requirements of the used inertial sensors (ii) to understand if and/or how these requirements are in relationship with the analysed populations and (iii) improving the basic knowledge of the gait acceleration signal, will permit to correctly and consistently -with the population- use of the metrics and their parameters since they directly or indirectly manage the signal in the frequency domain. The aim of the present study was to evaluate the harmonic content of the trunk acceleration signal during gait of nine different age populations to cover the entire life span. To do this, spectrum features: fundamental frequency, the frequency corresponding to the 50, 90, 95 and 98% of the signal power of the three, antero-posterior (AP) medio-lateral (ML) and vertical (V), acceleration directions were calculated.

II. MATERIAL AND METHODS

Nine age groups, from 7 to 85 year-old, of 10 healthy subjects each were recruited (see Table 1).

TABLE I
DETAILS OF AGE GROUPS: MEDIAN, MINIMUM AND MAXIMUM VALUES.

Description and acronym	Age [year]	Weight [Kg]	Height [cm]
7-years old children (7YC)	7 (7, 7)	29 (22, 37)	129 (119, 134)
9-years old children (9YC)	9 (9, 9)	34 (22,45)	140 (138,145)
15-years old adolescents Female Not Grown (15YAf)	15 (15,15)	54 (49, 74)	162 (147, 172)
15-years old adolescents Male Not Grown (15YAm_NG) [7]	15 (15,15)	64 (49, 74)	172 (169,176)
15-years old adolescents Male Grown (15YAm_G) [7]	15 (15,15)	59 (46, 65) Δw=2 (-1, 4)	172 (160,175) Δh=3.6 (3, 4)
25-years old adults (25YA)	25 (22, 26)	70 (48, 86)	168 (154, 187)
45-years old adults (45YA)	45 (41, 48)	74 (45, 100)	174 (155, 193)
65-years old adults (65YA)	65 (62, 69)	85 (68, 120)	176 (164,186)
85-years old elderlies (85YE)	85 (84, 91)	74 (57, 90)	177 (160, 175)

Two tri-axial wireless inertial sensor (OPAL, Apdm USA) were fixed: one on the lower back and one above the ankle needed for the stride detection [10]. The participants walked at self-selected speed for about 30 seconds along a straight path. Trunk acceleration was recorded with a sampling frequency (f_s) at 128 Hz. For all the subjects, an integer number of strides to cover at least a time duration of 20 seconds were analysed. The analysed strides raged from 23 (7YC) to 14 (15YAf); moreover the maximal signal duration was 21.3 s. Fundamental Frequency (*FF*) and the frequency corresponding to the 50, 90, 95 and 98% of the normalized power of the trunk acceleration in the three directions ($f_{50,90,95,98\%\_ap,ml,v}$) were calculated. To avoid influence of the anthropometric parameters, *FF* was normalized (FF_{NORM}) according to Hof et al. [11]; whereas, in order to assess possible interference between the harmonic content and the fundamental frequency, all the other features were normalized ($f_{50,90,95,98\%\_ap,ml,v\_NORM}$) with respect to *FF*. Since the normal distribution was not verified on all the groups,

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median, 25- and 75-percentile values were calculated.

III. Results

FF ranged from a maximum of 1.1 Hz, for the 7 year-old, to a minimum of 0.88 Hz for the male grown adolescents. FF_{NORM} showed different trend in respect to *FF* (see Fig 1).

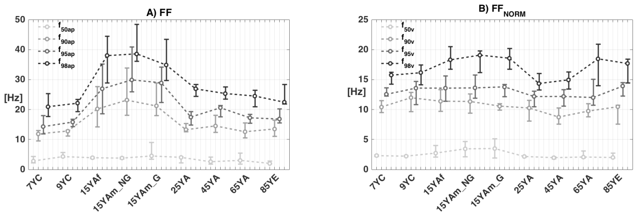

Figure 1: Median, 25th and 75th percentile of FF and FF_{NORM}, panel A and B respectively, for all the age groups.

$f_{98\%\_ap}$ showed a higher value (45Hz) for adolescent groups and lower one (20Hz) for 9YC. In V direction instead, $f_{98\%\_v}$ ranged from 20 Hz (all 15YA, 65YA and 85YE) to 15 Hz (25YA). No trends were observed for ML direction with age. The same trends were found for all the normalized features.

IV. Conclusion

To evaluate the harmonic content of the trunk acceleration signal during gait, of nine age groups from 7 to 85 years-old, fundamental frequency and frequencies corresponding to the 50, 90, 95 and 98% of the signal power were calculated.

The obtained FF values suggest that, in according with other studies [12], [13], the fundamental frequency corresponds to the stride frequency (cadence). Studies [14], [15] affirm that modifications in gait pattern, after 5-7 years old, are more influenced by changes in height than by modification of the motor control system. In order to understand how much -the observed FF changes- are due to physical characteristics, the normalization [11] by anthropometric parameters of the fundamental frequency (FF_{NORM}) was performed. From 7 year-old to 45 year-old close values of FF_{NORM} were found, confirming that stride frequency changes are due to anthropometric conditions. On the other hand, different behaviour for male grown adolescents and elderly (YA65 and 85YA) was found. In particular, male grown adolescents showed lower values than not grown peers and a decreasing of FF_{NORM} values from YA65 to YA85 was observed. These suggest a change/involvement of motor control system for the adolescents [7] and also a comorbidity contribute for the elderly [16], [17]. The choice to normalize the $f_{50,90,95,98\%\_ap,ml,v}$ with respect to the *FF* was performed in order to evaluate if the fundamental frequency of each population could influence the harmonic content of the signal. The obtained results showed similar values and trends, for normalized and not features, suggesting that the observed differences are peculiar of the populations. Values of $f_{50,90,95,98\%}$ highlight how the spectrum, in AP and V direction, is characterized by a peak at low frequency (around 3.5 Hz) and then by a uniform and low power band, wider in AP than in V direction. Instead ML direction is marked by a flat spectrum.

In general, the results of the present study suggest operative indications about how the trunk acceleration signal should be elaborated: (i) if the harmonic content is directly managed not less of 20 seconds of signal within a integer number of strides (about 20 stride) must be analysed, allowing a correct and reliable spectral analysis of a discrete, periodic and finite duration signals; anyhow, in all the elaborations a reliability of the used metrics has to be guaranteed [4]; (ii) to ensure a 98% of the harmonic content of the signal a sampling frequency higher then 90 Hz for the adolescents and than 60 Hz for the other age population should be used.

In order to further and strengthen improve the elaboration of trunk acceleration more researches are necessary; focusing on if and how the acquisition parameters, mainly the sampling frequency, change the values of indexes and metrics used to evaluate gait performance.

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