Assessment of Gait Harmony in Older and Young People

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Abstract: Recent studies have found that in normal human walking the *stance* and *swing* phases are approximately in proportion to ϕ, the golden ratio. This could provide an interesting tool in human gait analysis, in diagnosing pathological conditions or in analysing the walking performance of a subject. However, the assessment of gait harmony was provided in previous studies by means of optical systems, which are not ideal for clinicians, because of non-portability, high-costs, and necessity of expert supervisor skills. In addition, the assessment regarded mostly middle-aged or aged people. Differently, this work is based on wearable technology to sense human walking, and reports a comparison between elder and young people. Results demonstrate how elders adopt a walking style which better minimizes the energy expenditure.

1 INTRODUCTION

Human walking is extensively studied in different research fields, such as physiology, computer animation (Multon et al., 1999), control theory, biomechanics (Cappellini et al., 2006; Bauby and Kuo, 2000), and so on. Gait analysis supports medical diagnosis (Jankovic, 2008) and allows developing humanoid robot locomotion (Ames et al., 2012). Nevertheless human walking is still far to be completely understood, and new findings are more than welcome.

Walking is a succeeding of movements, periodically repeated (Figure 1), named gait cycle (Ayyappa, 1997), which can be essentially related to two main phases: a *stance phase* (or, simply, *stance*) and a *swing phase* (or, simply, *swing*). The *stance* is when the foot is in contact with the ground, the *swing* is when the foot in in the air moving forward. During walking one leg is in *stance* and the other leg in *swing*.

The *stance* is, in turn, divided into three phases: hell-strike, foot-flat, foot-off. Analogously, the *swing* consists of: acceleration, mid swing, deceleration.

Recent studies suggested how in normal human gait of healthy adults (49±19yo) the *stance* and *swing* ratio of a gait cycle seems to be close to ϕ, feature named "Gait Harmony" (Iosa et al., 2013), with $\phi \cong$ 1.618 being the "golden ratio", an irrational number. This ratio seems to be altered in adults (67.23±10.65yo) suffering from pathological conditions affecting the walking movements, such as Parkinson disease (Iosa et al., 2016b). Morehover the closeness to ϕ was associated to a walking with minimal energy expenditure (Serrao et al., 2017).

All those works were based on measurements made by means of video-capturing and video-motion analisys systems, which are meaningfully considered as a standard-gold, but with the drawbacks to be very expensive, highly technical, non-portable, not-practical for clinical environments or multisite clinical trial equipments. In addition, all those works did not considered very young people, mainly investigating middle-aged or aged people.

Differently, useful objective measures of human walking need to be cost-effective, portable and easy to andle, as in can be by means of wearable electronics (Greene et al., 2015; Hsu et al., 2014; Spain et al., 2012; Solomon et al., 2015; Bonora et al., 2015), and have to take into account a wider age-range, including young people.

Therefore, our work is devoted to consider the evidence of the presence of ϕ, if any, according to measures acquired by means of inertial wearable sensors in healthy people ranging from young to aged.

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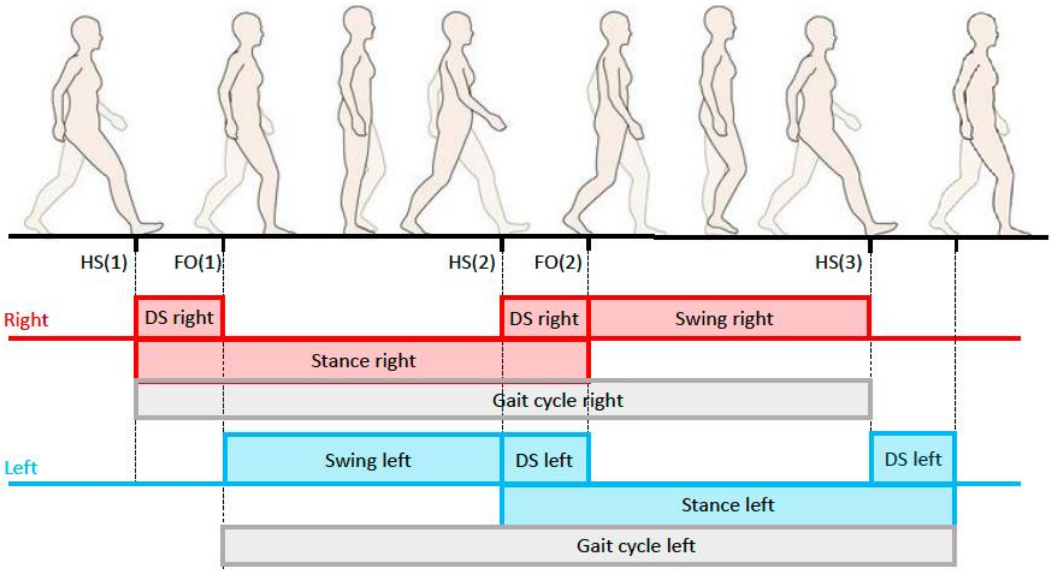


Figure 1: The gait cycle, with stance and swing phases.

The rest of this work is structured in three parts: the first dealing with materials and methods, in which the golden ratio will be properly introduced and experimental procedure and data analysis methods detailed; the second part about obtained results; the third part related to discussion and conclusion.

2 MATERIALS AND METHODS

2.1 Golden Ratio

The "golden ratio" is the irrational number $\phi = (1+\sqrt{5})/2 \cong 1.618$, it can be defined as the proportion between two quantities A and B such that $A/B = (A+B)/A$.

$$A/B = (A+B)/A \tag{1}$$

Considering $x = A/B$, we have:

$$x = 1 + 1/x \tag{2}$$
$$x^2 - x - 1 = 0 \tag{3}$$

which has two real solutions, $x_{1,2} = (1 \pm \sqrt{5})/2$, the positive solution being ϕ, as the only with a physical meaningful.

This number is considered to have particular aesthetic properties, and it is often used by artist and architects in their work (Akhtaruzzaman and Shafie, 2011). The "golden ratio" is also present in many patterns in nature and science in general, as botanics, biology, physics and engineering (Guerreiro and Rothen, 1995; D'Amico et al., 2014; Davis and Altevogt, 1979; Yamagishi and Shimabukuro, 2008; Kajiyama et al., 2007). From eqs. (2) and (3) the two most important properties of ϕ are easily obtained:

$$1/\phi = \phi - 1 \tag{4}$$
$$\phi^2 = \phi + 1 \tag{5}$$

i.e. ϕ^{-1} and ϕ^2 maintain the same fractional part of ϕ, while the integer part change of an unit.

2.2 Gait Cycle

The (bipedal) *gait cycle* (GC) is the sequence of movements during locomotion, made of repetitive pattern consisting in a *stance phase* (ST, one foot on the ground) and a *swing phase* (SW, the same foot off the ground), so (Figure 1)

$$GC = ST + SW \tag{6}$$

On turn, the *stance phase* is composed of a *single support phase*, when only one foot sustains the body, and a (splitted-in-two) *double support phase*, with both foot on the ground. Under the reasonable hypotesis of a symmetric gait, the *stance phase* can be considered as the sum of the (splitted-in-two) *double support phase* (DS) with the (controlateral) *swing phase* that is of the opposite foot), so

$$ST = DS + SW \tag{7}$$

2.3 Golden Ration and Gait Cycle

With the aim of investigating the possibility to identify the golden ratio within the gait cycle, as in

(Iosa et al., 2013), we assume $\phi = ST/SW$ so that, according to eq. (1), we have:

$$\phi = \frac{ST}{SW} = \frac{ST + SW}{ST} = \frac{GC}{ST} \quad (7)$$

From eq. (4), it results:

$$\frac{SW}{ST} = \frac{ST}{SW} - 1 = \frac{ST - SW}{SW} \quad (8)$$

and considering eqs. (6) and (7), we can write:

$$\phi = \underbrace{\frac{ST}{SW}}_{GR1} = \frac{ST}{GC - ST} = \underbrace{\frac{GC}{ST}}_{GR0} \quad (9)$$

$$\phi = \underbrace{\frac{ST}{SW}}_{GR1} = \frac{DS + SW}{SW} = \underbrace{\frac{SW}{DS}}_{GR2} \quad (10)$$

where, according to the literature (Iosa et al., 2016a):

- $GR0 = \frac{GC}{ST}$
- $GR1 = \frac{ST}{SW}$
- $GR2 = \frac{SW}{DS}$

2.4 Participants

Four healthy elderly (4 men mean age: 70±10 years old), forming a first group, and five healthy young (2 girls and 3 men, all 22 years old), forming a second group, with no pathological or orthopedic impairements, were enrolled in this study. The local ethical committee approved the study, which was designed in accordance with the principles of Declaration of Helsinki on studies of human subjects.

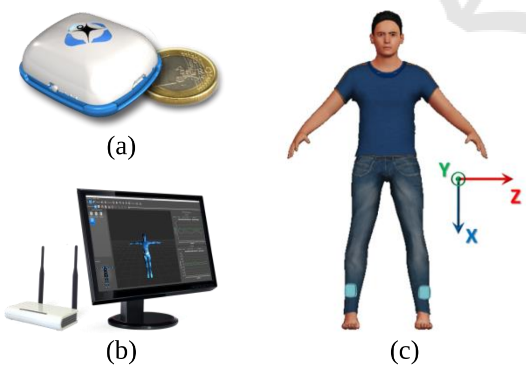


Figure 2: (a) "Movit G1" sensor, (b) the receiver unit, which collects data wireless sent by each sensors and communicate with a personal computer running "Captiks Motion Studio", and (c) the locations of each sensor on the body of the subject.

2.5 Wearable Electronics

The wearable electronics used in this study was made of inertial sensors, singularly termed "Movit G1" (Figure 2a, by Captiks Srl, Rome, Italy), which can measure 3D linear accelerations, 3D angular velocities and orientation (Alessandrini et al., 2017).

The system synchronously allows the capture of the data from a network of "Movit G1" sensors. Data from sensors were wireless acquired in real time, visualized on a screen and stored on a personal computer by means of a dedicated software, termed Captiks Motion Studio (Figure 2b, by the same manufacturer).

The measuring range was set to ±2g for the accelerometer (sensitivity: 16,384 LSB/mg) and 2000/s for the gyroscope (sensitivity: 16.4 LSB/°/s), with a sampling frequency of 50Hz.

Two sensors, forming a sort of small-network, were applied to each participant, in turn, on the ankles through elastic bands (Figure 2c).

Gait analysis were performed in post processing on Matlab® environment.

2.6 Data Analysis

In order to obtain the gait time events we analyzed the z-axis angular velocities recorded by gyroscopes. According to (Sabatini et al., 2005), a good approximation for the *foot-off* (FO) and *heel-strike* (HS) time is given by the instant of maximum foot rotation velocity, assuming the clockwise convention. More precisely, for the same leg, the *foot-off* event occurs at the maximum which follows the zero angular velocity instant, i.e. after the *stance phase*, and the *heel-strike* occurs at the succeeding maximum, namely the one after the *swing phase* (Figure 3).

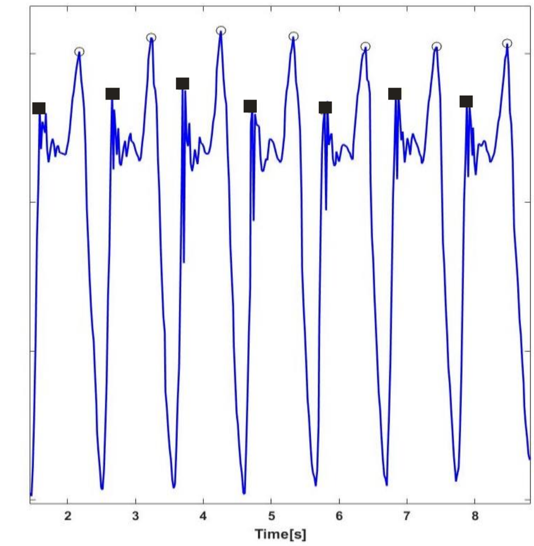
From the knowledge of the *heel-strike* and *foot-off* events, assuming that the *gait cycle* starts with an *heel-strike* from the right leg (analogusly for the left), according to Figure 1, the gait cycle timing parameters can be easily obtained as follows:

$$ST = FO(2) - HS(1) \quad (11)$$
$$SW = HS(2) - FO(1) \quad (12)$$
$$DS = FO(1) - HS(1) \quad (13)$$
$$GC = HS(3) - HS(1) \quad (14)$$

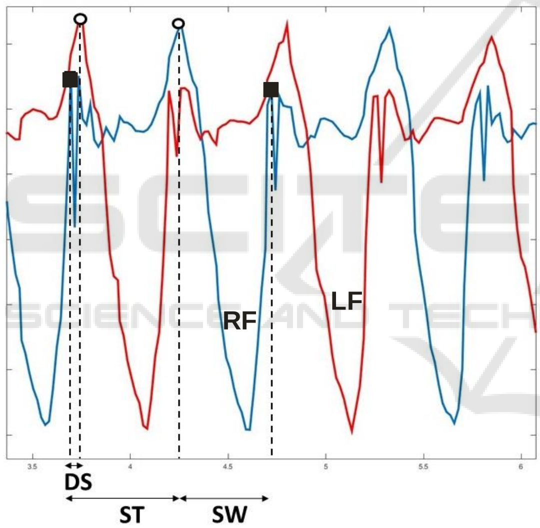
where the event number is evidenced in parenthesis.

2.7 Protocol

Movit sensors were placed on ankles, as schematized in Figure 2c.



(a)



(b)

Figure 3: (a) measured foot velocities of 7 gait cycles and estimation of *heel strike* (■) and *foot-off* (o) time events, (b) estimation of gait cycle parameters combining measurements of right foot (RF) and left foot (LF).

A timed up and go test were performed: the subject get up from a chair, stright walked 3 meters, turned around, walked back, and sit down. All subjects were instructed to avoid leaning on arms to stand up, and to walk at their self-selected, usual speed. Only the central part of the pathway was selected to perform the analysis of the parameters. Spatial-temporal parameters were computed among at least 6 strides (3 per limb).

3 RESULTS

Results are reported in Table 1. Both groups showed a similar gait cycle duration, respectively 1.182s and 1.2525s in average, 0.0705s more for young. DS was shorter in young than elders, 0.20s vs. 0.28s. This is reflected especially on the $SW/DS = GR2$ ratio, which resulted different between two groups, 2.795 for young respect to 1.700 for elders. The $ST/SW = GR1$ ratio was closer to ϕ for elders with 1.642 with respect to 1.390.

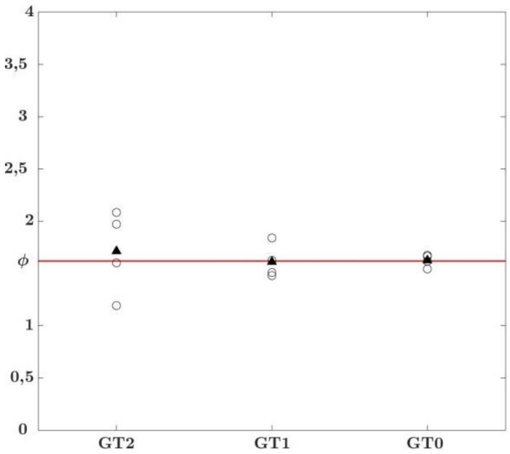
Table 1: Gait parameters of participants, E1-E4 elderly, S1-S5 young. SW, ST and DS are respectively Swing, Stance and Double Support, in [s]. Rows $\overline{E}$ and $\overline{Y}$ represent mean values for elderly and young, respectively.

	SW	ST	DS	$GR0$	$GR1$	$GR2$
E1	0.45	0.83	0.32	1.547	1.837	1.420
E2	0.49	0.73	0.26	1.677	1.480	1.863
E3	0.49	0.80	0.27	1.615	1.626	1.850
E4	0.45	0.73	0.27	1.616	1.624	1.666
$\overline{E}$	0.47	0.77	0.28	1.614	1.642	1.700
Y1	0.55	0.82	0.26	1.676	1.484	2.090
Y2	0.47	0.60	0.12	1.794	1.261	3.845
Y3	0.45	0.58	0.13	1.777	1.286	3.500
Y4	0.53	0.68	0.18	1.763	1.296	2.960
Y5	0.47	0.76	0.30	1.618	1.623	1.581
$\overline{Y}$	0.49	0.08	0.20	1.726	1.390	2.795
$\|\Delta\|$	0.02	0.08	0.08	0.112	0.252	1.095

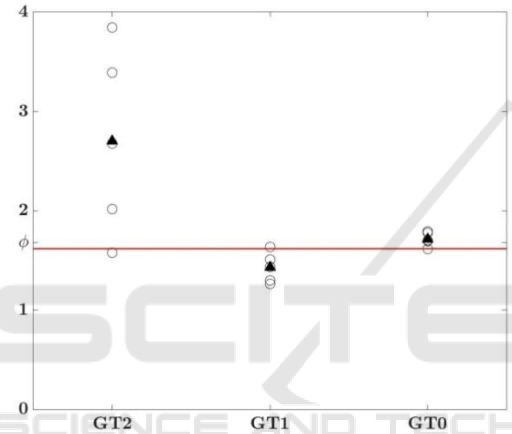
$GR0$, $GR1$ and $GR2$ are plotted in Figure 4, where it results that in elders all proportions are closer to f and show less spread than those for young participants. It is notable that results about elders are similar to those obtained in a previous study, in which the mean age was of 49 years old (Iosa et al., 2013), comparisons are shown in Table 2.

Table 2: Comparisons between mean value and standard deviation of GR0 and GR1 of elders enrolled in this study and results presented in (Iosa et al., 2013).

	Previous work	Current work
$GR0$	1.684±0.357	1.699±0.179
$GR1$	1.629±0.173	1.614±0.127



(a)



(b)

Figure 4: Comparison between the three walking parameters ratios and golden section for (a) elders and (b) young. Clear circles represent the values for each participant, dark triangles represent the mean values.

4 DISCUSSION

The results confirmed that the proportion between stance are in accord to previous studies, which gives a confirm that wearable sensors could provide estimation of the gait parameter ratios as good as visual systems, giving an easy-to-use alternative to the current methods, that would be helpful in a prospective for a possible clinical usage of those figures.

Moreover, comparisons had shown that the relation between gait cycle parameters and golden section is way more evident in elders, who presented a mean value of $GR1$ very close to ϕ,. The differences between young and elders may be due to a different style of walking. It can be note that the double support phase is longer in elder that in young, for parity of gait cycle duration, this can be due to a more powerful push by the stance leg during the double support phase in young people. Elders may choose the walking stile that more optimizes the energy expenditure, instead of young, who may prefer a more rapid movement, this interpretation could be in accord to (Serrao et al., 2017), in which is said that the relation between gait parameters and golden ratio may be due to energetic reasons. However from these results seems that a deviation of gait parameters from the golden ratio doesn't mean necessarily that the walk is abnormal. This suggest that more comparisons are needed, for example between man and woman, or children and adults, for a good comprehension of the effective presence of the golden ratio in human walking, and in order to explain when and why the gait parameters ratios are far from this number.

5 CONCLUSIONS

In this work we had provide independently that the stance and swing duration are in proportion with the golden ratio, using wearable sensors for the experimental setup. Moreover a comparison between elders and young has be done, showing that the relation between gait parameters and f could be more evident in elders that in young people. However the low number of participants doesn't make those results statistically accurate and more studies are needed for validate the conclusion obtained in this work, anyway it still constitute a proof of concept, which could provide a starting point for future works.

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