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Research Article

Perceiving Harmony Behind Walking: A Study on Healthy Subjects

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Abstract

This study aims to investigate how the naturalness of movement is perceived in a sample of healthy participants. Specifically, 256 people (34.2 ± 10.8 years; M = 89; F = 167) were asked by means of an online questionnaire to give an evaluation of the naturalness of a video showing a girl walking along a walkway.

We presented four videos of which only one had been recorded in „normal" forward walking and at a comfortable speed and which presented a gait ratio coinciding with the golden proportion. For the other three we have instead recorded some motor tasks in which the same person walked in a different way: walking back, slowly, quickly.

The participants evaluated each video, without knowing how they have been recorded: the videos were all modified so as not to seem too different from the forward one in order to not induce a bias in the evaluation.

The results show that the subjects preferred the video in which the girl walked in forward golden mode.

Keywords: *Golden Ratio; Gait Cycle; Gait Analysis; Vision; Perception*

Introduction

Humans perceive biological motions with great accuracy and speed also when the visual stimuli has been unfamiliar, altered or even impoverished [1]. Furthermore, humans are able to recognize atypical walking patterns and/or motion inconsistencies with respect to normal natural human walking [2]. Even when walking stimuli has been impoverished until simplifying biological motion into a cluster of moving points, subjects were still able to identify biological movements on the basis of their temporal variation of their spatial arrangement [3].

The study of the movement perception could have a very important applicative value, especially in clinical context. In fact, many pathologies involving a motor deficit are also related to the presence of deficits in the awareness of one's own motor skills [4]. Specific results conducted on the motor imagery of stroke patients showed that many patients in the early stages of the disease are not completely aware of their motor limitations [5]. Motor imagery has been defined as a mental rehearsal of an action without its actual performance [5]. Also, patients with Parkinson's disease showed different results about the judgement and the predictions of motor actions of other agents depending on whether the action was imagined or actually seen to perform [6]. These results about the judgment of a motion might suggest the existence of some models of perceptive categorization that guide our way of perceiving movement, based on physical features embedded into the stimulus. According to this theory, it has been shown that the brain regions of occipito-temporal cortex responding to biological motion were more active when the locomotion was reproduced virtually altering the physical law of gravity applied to human body [7].

Another possible feature related to walking is its intrinsic harmony. It has been suggested that the harmony of walking is due to a specific proportion between the duration of the stance and that of the swing phase of each stride [8]. The stance is the phase of a stride in which the foot is in contact with the ground, whereas the swing is the phase in which the foot is moving forward in the air. This proportion was found equal to the so-called golden ratio (indicated with ϕ) that is an irrational number obtained as the mathematical solution of the problem to divide a segment in a manner that a the ratio between the longer (a) to the shorter (b) parts of the segment is equal to the ratio between the whole segment (a +b) and the longer part (a). This relationship can be expressed as a: b = (a + b): a.

Defining *x* as the ratio between and hypothesizing b = 1, the previous equation can be written as it follows that x from which derives the equation having two roots, one negative (and hence impossible for the geometrical problem) and one positive that is .

In human walking, it was found that this proportion is preserved: the stride has been divided by the foot off in a manner that the ratio between the stance and swing durations is equal to the ratio between the stride and the stance durations, and both equal to ϕ [8]. This number (ϕ = 1.618…) was not found only in human walking but also in human anthropometry as the proportion between stature and height of navel from the ground, in the rhythm of human heart as the proportion between systole and diastole durations, in seeds and leaves dispositions in plants, as well as in many other fields of psychology, physiology and biomechanics [9].

Probably for the presence in human anthropometry of this number, since the 5th century b.C., artists considered the golden ratio as a beautiful and pleasant proportion, and built the sculptures of human subjects, such as the Doryphoros of Polykleitos and the Venus of Milo, in golden ratio. This proportion was also used in artistic works not replicating human figures, for example it was used by Phidias as the proportion between the basis and the height of the façade of Parthenon [10].

Zeising considered this "law of proportion" as a "yardstick of aesthetic judgments" [11] and from his first conceptualizations, several studies followed in order to verify the if golden ratio has been preferred than other proportions in an aesthetic judgment. This judgment could hence be intrinsically related to a judgment of naturalness, being the golden ratio a natural proportion for human bodies, walking, hearth beating and reported in many artworks [9].

However, it has never been investigated the ability of humans of judging as more natural a walking in golden proportion with respect to walking in other stance to swing proportions. This lack can be due to the fact the physiological alteration of stance to swing ratio (gait ratio) is not simple and can be obtained slowing or speeding up the walking speed, but in this case, the judgement can be affected by the difference in velocity. However, to overcome this limitation, we used a software developed for altering videos with the aim of investigating if humans would prefer as more natural a walking performed by an actor at golden ratio with respect to other proportions, all shown at the same walking speed. The hypothesis is that the naturalness of walking may depend on the intrinsic harmony given by the presence of this golden proportion.

Materials and Methods

Participants

The sample was composed of 256 (M = 89; F = 167) healthy subjects who voluntarily participated to the experiment with a normal or corrected-to-normal vision, with an average age of 34.2 ± 10.8 years. The sample presents a heterogeneous educational and cultural level, with an average schooling of about 16.8 ± 2.9 years.

Procedure

The judgment test was formed by a questionnaire administered, anonymously, through an available online software (a research modality that is currently spreading in psychosocial research [12]). The online questionnaire consisted of a first part in which demographic data about sample have been collected and of a second part in which videos have been presented. In this latter part, the voluntary participants

saw four videos of a lady walking forward along a corridor. The point of view was lateral with respect to walking, so the scene coincided with the sagittal plane of the lady. Participants were required to judge the naturalness of that walking with a Numeric Rating Scale [13] going from 1 (completely unnatural) to 10 (perfectly natural).

As stated above, the alteration of stance and swing phases is difficult to be voluntarily obtained, but it depends on speed and modality of walking. In turn, the judgment about naturalness can be influenced by speed and direction of walking, so we used a software for video alteration in order to obtain the final four videos in which the walking speed is roughly the same, the direction was the same and only the gait ratio was different (See table 1).

The walking lady was video recorded during comfortable forward walking, slow forward walking, fast forward walking, and comfortable backward walking. Then the velocity of video reproduction was altered with the aim of reducing the speed variability among the videos and analyzing only the differences in gait ratios. So, we increased the speed of slow walking, slowed down that of fast walking, and reversed and slightly speeded up the reproduction of backward walking. Final obtained proportions were those reported in table 1, with the variability of speed reduced from 48%. Differently from real human walking, our procedure did not alter the gait ratio, because it is proportion of durations both slowed or speeded.

Walking condition	Original Video			Video showed to subjects		
	Direction	Speed	Ratio	Direction	Speed	Ratio
Normal	Forward	1.4 m/s	1.62	Forward	1.4 m/s	1.62
Slow (speeded)	Forward	0.5 m/s	1.38	Forward	1.2 m/s	1.38
Fast (slowed)	Forward	1.7 m/s	1.63	Forward	1.2 m/s	1.63
Backward (reversed)	Backward	1.0 m/s	1.53	Forward	1.2 m/s	1.53
Variability	**1 out of 4**	**45%**	**8%**	**0 variability**	**8%**	**8%**

Table 1: *Video alteration procedure. Gait direction, speed and ratio between stance and swing durations are reported. Variability was computed as the variation coefficient among the data of the four videos.*

Statistical analysis of the subjects' responses were performed using IBM SPSS statistical software version 23. Considering that the obtained data represent ratings responses, we performed non-parametric statistical analysis Friedman's analyses in order to assess differences between participants' ratings to videos, and the Wilcoxon test for post-hoc analyses. For the former analysis, the alpha level of significance was set at 0.05, whereas for the latter it reduced according to Bonferroni's correction at 0.025. Variability reported in table 1 has been computed as the percentage ratio of standard deviation and mean among the four videos for speed and gait ratio.

Results

As shown in figure 1, the most preferred video was that recorded during normal walking. Also, the slowed video, in which the lady walked at fast speed, was judged as natural, whereas the reversed back walking and that speeded up slow walking video were judged as poorly natural, despite the walking speed was similar among the videos. The distributions of subjects' responses are shown in figure 2. Friedman's analysis showed a statistically significant difference of ratings among these four conditions ($p < 0.001$). Post-hoc analyses performed using Wilcoxon test highlighted that both normal walking and slowed fast walking resulted significantly more preferred than reverse backward walking ($p < 0.001$ for both) and speeded slow walking ($p < 0.001$ for both). The former two preferred condition were not significantly different ($p = 0.028 > 0.025$) and were significantly correlated each other ($R = 0.440$, $p < 0.001$). The latter two less preferred condition were not significantly different ($p = 0.131 > 0.025$) and were significantly correlated each other ($R = 0.616$, $p < 0.001$). The judgement about normal walking was not correlated with these less preferred conditions (reverse backward walking: $R = -0.032$, $p = 0.606$; speeded slow walking: $R = 0.023$, $p = 0.718$).

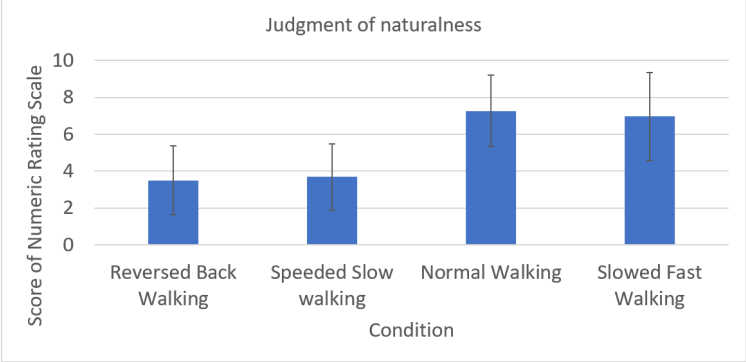

Figure 1: *Mean and standard deviation of the score of Numeric Rating Scale related to the judgment of naturalness.*

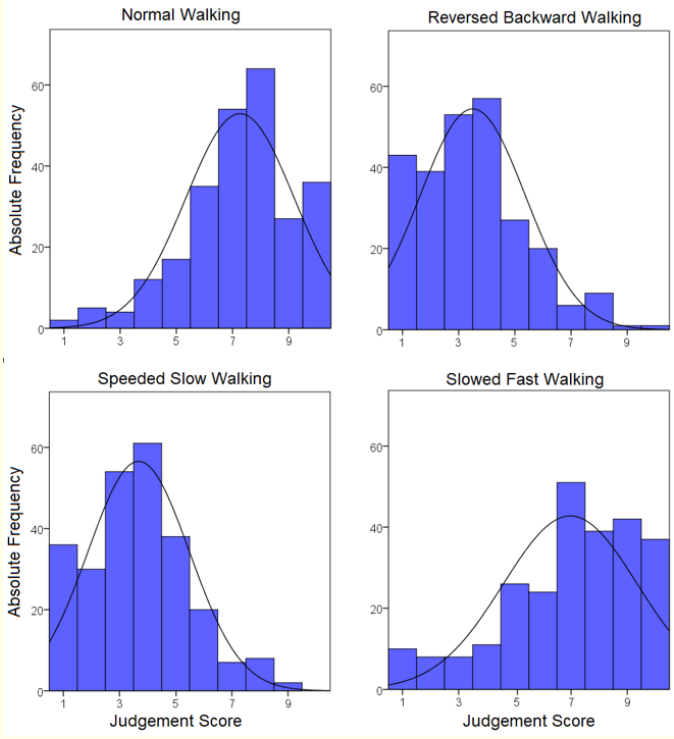

Figure 2: *Distributions of number of subjects (absolute frequency, blue bars) selecting a specific judgment score for the four conditons, with normal distribution (black lines).*

Discussion

As expected the most preferred video was that recorded during normal walking. It was conceivable that subjects were able to recognize the not altered video as that of real natural motion. This aspect can be related to the high capacity of subjects to recognize human biological motion [1,2]. However, the most important result of our study is that the slowed fast walking was judged as natural as well as

normal walking. It was not different from the other conditions in terms of speed, but just in term of gait ratio. The gait ratio of this condition was 1.63, closer to that of normal walking and hence to φ, than the gait ratios of the other two conditions, both judged as poorly natural. Also, the distribution of responses reported in figure 2 clearly showed similar subject's judgments for normal and slowed fast walking on one hand, and on the other hand similar distributions for speeded slow walking, having a gait ratio of 1.38 and reversed backward walking with a gait ratio of 1.53.

These findings support our hypothesis that the naturalness of walking is related to the golden ratio that provide an intrinsic harmony to walking, as previously suggested [8].

In a previous study [14], the spatial-temporal parameters of the gait of healthy adults, were measured during different locomotor tasks: forward walking performed at slow, comfortable and fast speed, and also backward and lateral walking, stepping in place, stair ascending and descending. Forward walking at comfortable speed, backward walking and stair descending showed a proportion between stance and swing durations close to the golden ratio. In the present study, backward walking was performed by the actor at quite slower speed and with a gait ratio smaller than φ. It resulted in a low judgment of naturalness. The fact that we just used one actor for the videos allowed us to do not have variability among conditions related to the walking subject, but at the same time it can be seen as a limit of our study for the above reason. Another limit is the absence of measures of response time or other cognitive features of our sample, but the simplicity of our questionnaire allowed us to enroll many subjects (n = 256).

In the scientific literature there are many studies on the gait analysis or on the perception of stimuli which are required to judge as pleasant, both for healthy and pathological subjects. But, at the best of our knowledge, this is the first one investigating the naturalness of gait harmony in relationship to the autosimilar feature of walking performed in golden proportion.

The alteration of this parameter is often used in clinical settings for detecting gait deficits [15]. In general, harmony, related to the concept of kinetic melody of Luria [16], could be an important determinant of physiological gait [17]. This idea is also supported by a recent work showing that golden walking is the condition in which efficiency of gait is maximized (i.e. there is a minimum of energy necessary for walking) [18]. Even artificial intelligence of technological systems could be used to recognize abnormal or undesired human movements from a video recording, such as falls of a patient [19,20]. It could be intriguing to train artificial intelligence in recognizing not golden gait in pathological conditions or using visual or acoustic stimuli developed in this proportion for training patients in recovering an harmonious walking.

Conclusion

Humans have the ability to recognize a movement as biological, even when it is altered or poorer than the normally seen movement. Our study showed that the naturalness of walking was related to its intrinsic harmony more than its speed, and that harmony was related to the specific proportion between the stance and swing phase, coinciding with the golden ratio, a number already recognized in art and biological sciences as a feature of harmony.

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Conflict of interest

Authors declare no conflict of interest.

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