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EFFECTS OF CONCURRENT DISCRIMINATION TASKS ON GAIT IN HEALTHY SUBJECTS

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ABSTRACT

The objective of this study was to determine the cost of performing a concurrent discrimination and decision-making task (dual-task cost, DTC) while walking to gait kinematics and dynamic stability. The study included 28 healthy young adults without any motor and/or cognitive disorder. An intra-group repeated measures design was applied. Participants were instructed to walk either under normal conditions or while performing an executive task. The executive tasks involved discriminating the color of the lights of two traffic lights and stopping as rapidly as possible when the traffic lights turned red simultaneously. A kinematic analysis of the gait cycle was performed by 3D photogrammetry. Gait cadence and step variability were measured using the GAITRite® treadmill. The results obtained confirm that the duration of single-support during the two steps of the gait cycle tends to decrease in dual task conditions. An especial impact was observed on step length, which explained the 2% reduction in the velocity of displacement of the center of mass. Variability in step time and length increased with dual tasking. No differences were found among dynamic stability factors. We propose using a DTC differential for subjects with motor and/or cognitive disorders as compared to healthy individuals.

Key words: motor control, biomechanics, neuropsychology, gait, dual- task

EFECTO DE LAS TAREAS CONCURRENTES DISCRIMINATORIAS EN LA MARCHA DE PERSONAS SANAS

RESUMEN

El objeto de este trabajo ha sido evaluar el costo que produce una segunda tarea concurrente de discriminación y toma de decisiones (DTC), sobre los parámetros cinemáticos y la estabilidad dinámica de la marcha. Han participado 14 hombres y 14 mujeres, todos ellos adultos jóvenes sanos y sin patologías motoras y/o cognitivas. Se ha utilizado un diseño intragrupo de medidas repetidas donde cada participante debía de realizar una marcha normal y otra con tarea concurrente ejecutiva. Para la evaluación de los parámetros cinemáticos del ciclo de marcha se han utilizado técnicas fotogramétricas 3D y para el análisis de la cadencia y la variabilidad del paso se ha utilizado el pasillo de marcha GAITRite. Los resultados han constatado que la realización de la tarea concurrente propuesta tiende a reducir el tiempo de la fase monopodal de los dos pasos del ciclo de marcha y, especialmente, sus respectivas longitudes, siendo la longitud de paso la principal causa de la reducción del 2% de la velocidad de desplazamiento del CG. La variabilidad del tiempo de paso y de sus respectivas longitudes se ha incrementado por efecto de la tarea concurrente propuesta. No han existido diferencias entre las medias de los factores relacionados con la estabilidad dinámica. Se sugiere utilizar un diferencial de DTC entre personas con déficit de recursos motores y/o cognitivos, con respecto a las personas en plenitud de recursos.

Palabras clave: control motor, biomecánica, neuropsicología, marcha, tarea dual

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INTRODUCTION

Walking is a complex task that involves the activation of sensory nerves and cognitive structures (Harada, Miyai, Suzuki, & Kubota, 2009; Iseki, Hanakawa, Shinozaki, Nankaku, & Fukuyama, 2008; Sheridan & Hausdorff, 2007; Yogev-Seligman, Hausdorff, & Giladi, 2008). Performing a concurrent task while walking compromises the performance of competing resources and processes, which may affect gait pattern. The extent to which gait performance is affected will depend on the task involved and on individual capabilities (Abbud & DeMont, 2009; Kelly, Janke, & Shumway-Cook, 2010; Nordin, Moe-Nilssen, Ramnemark, & Lundin-Olsson, 2010).

The dual-task paradigm has been widely used to assess the effects of concurrent tasks on gait pattern, a phenomenon that is known as "dual-task cost" (DTC). The relationship between DTC and gait cycle time and space parameters has been the subject of intense research. Studies consistently show that concurrent secondary tasks involving verbal fluency, working memory, or mental tracking have an impact on gait speed, cadence and step length. Thus, DTC has been proposed as an indicator of functional performance and a predictor of some neuroegenerative diseases (Al-Yahya, Dawes, Smith, Dennis, Howells, & Cockburn, 2011; Belghali, Chastan, Davenne, & Decker, 2017; Hardy, Perera, Roumani, Chandler, & Studenski, 2007; Palombaro, Craik, Mangione, & Tomlinson, 2006).

However, contradictory results have been obtained regarding the impact of executive discrimination decision-making tasks on gait (Al-Yahya et al., 2011). This type of tasks requires the use of selective attention to respond to a specific stimulus, which is common in complex, unstable environments (Nakamoto & Mori, 2012).

Therefore, walking in a changing environment requires the continuous adaptation of the programmed movement to the varying conditions (i.e. paying attention to stop when a traffic light turns red, or changing direction when another person gets in your way). Reprogramming movements requires the activation of cognitive and motor processes to rapidly detect and discriminate changes in the environment, inhibit the programmed step, and adapt to the new conditions. Inhibitory attentional control plays a crucial role in the DTC to gait performance. DTC is consistently attributed to the competition of limited resources, and to central nervous system impairment (Belghari et al., 2017; Nordin et al., 2010). However, healthy individuals without any cognitive or motor disorder have been reported to exhibit DTC to gait performance (Woollacott & Shumway-Cood, 2002). The underlying causes might be the input of the two visual streams together with facilitation strategies.

The input of the two visual streams is defined as the coordination of the ventral stream –associated with explicit awareness, which provides information on the probability of executing an action– and the dorsal stream – which is immediate and relatively rapid, and gathers visual cues implicit in movement control (Goodale & Westwood, 2004; Milner & Goodale, 1995). Thus, uncertainty caused by concurrent inhibitory tasks requires the dominance of the ventral system, which results in a reduction of the velocity of movement (Van der Kamp, Rivas, Van Doorn, & Savelsbergh, 2008). On the other hand, cognitive neurosciencists have suggested that an unexpected shift of direction or stop while walking require the use of a facilitation or high-order strategy to inhibit the programmed action and adapt the response to the new environment (Gao, Wong-Lin, Holmes, Simen, & Cohen, 2009). This response-inhibition process relies on two closely-related mechanisms: the first inhibits the activation of potential responses selected at the spinal level (impulse control), and the second selects a response among the most relevant ones (conflict resolution). Therefore, when a selective task is performed while walking, all potential responses are activated, thus requiring inhibitory signals at the spinal level, waiting for external information that will make a response prevail over the others (Duque, Lew, Mazzocchio, Oliver, & Ivry, 2010). The second inhibitory mechanism has been suggested to occur at the upper cortical levels, causing a delay in response (Schluter, Rushworth, Passingham, & Mils, 1998; Ivanoff, Branning, & Marois, 2009).

The two theories exposed above would explain the DTC to gait performance caused by a concurrent discrimination and decision-making task, regardless of individual motor capabilities. Notwithstanding the above, there is evidence that individual capabilities or resources influence the extent of DTC. Accordingly, our previous studies in patients with different degrees of neurological impairment suggest that gait speed and step length decrease as a result of the uncertainty caused by concurrent discrimination and decision-making tasks (Gutiérrez-Cruz, Miangolarra, & Rojas, 2016). Nevertheless, evidence is not conclusive due to differences in functionality among participants and the lack of reference data that would allow us to determine the differential cost with respect to healthy subjects.

The objective of this study was to determine the cost of a concurrent discrimination and decision-making task while walking to gait kinematics and dynamic stability in healthy young adults. We hypothesized that the cost of selective attention caused by a secondary task would affect time parameters, step length, velocity of displacement of the center of mass, and gait pattern variability. However, formulating a hypothesis on the dual-task cost to dynamic stability would be too audacious, as little evidence is available on this factor.

METHOD

Study Design

An intra-group, repeated measures design was applied to compare gait performance in two experimental conditions: a) *normal walking*, where participants were instructed to walk normally, and b) *performing a concurrent executive task while walking*, where participants were instructed to start walking when two traffic lights placed in front of them turned green simultaneously, and stop as fast as possible when the lights turned red.

Gait patterns were analyzed based on the time parameters of the gait cycle (Gutiérrez-Cruz et al., 2016). Spatial parameters were measured, including stride length, defined as the horizontal distance between two successive strikes of the right foot; left-step length, defined as the horizontal distance between the right heel strike and the left heel strike; right-step length, defined as the horizontal distance between the left heel strike and the right heel strike; the lateral distance between the left and the right heel strike were calculated. Swing width (amplitude) of the two legs during single support was calculated as the distance between the space traveled along the trajectory of the markers on the heels and the horizontal space traveled.

Participants

28 healthy young adults (14 women and 14 men) participated in this study. Participant selection was carried out using a quality of life questionnaire (WHOQOL-BREF) and an analysis of body composition by the InBody-230 system (Los Angeles, CA, USA). Based on the data and screening results obtained, the following inclusion criteria were established: a) Age ranging from 25 to 55 years; b) No history of previous disease, functional disorder, or visual deficit in the last six months; c) A mean score on the four dimensions of the WHOQOL-BREF questionnaire > 55% of the maximum score; d) A normal body composition. Table 1 shows data for characteristics of participants. As established by the local Ethics Committee, informed consent was obtained from all participants.

TABLE 1
Characteristics of the participants.

Características	**MEN (N=14)**	**WOMEN (N=14)**	**Total (N=28)**
Age (years)	44.9 ± 10.0	48.8 ± 6.7	46.7 ± 8.6
Height (m)	1.76 ± 0.06	1.63 ± 0.05	1.70 ± 0.09
Mass (Kg)	80.9 ± 8.3	63.0 ± 10.9	71.9 ± 13.2
Skeletal muscle mass (Kg)	35.8 ± 4.0	24.4 ± 3.2	30.7 ± 6.8
Skeletal muscle mass (%)	43.9 ± 3.9	38.9 ± 3.7	41.4 ± 4.5
Body fat mass (Kg)	18.7 ± 7.0	18.8 ± 7.0	18.76 ± 6.8
Body fat mass (%)	22.5 ± 6.8	29.0 ± 6.8	25.7 ± 7.4
Body mass index (Kg/m2)	26.4 ± 2.8	23.9 ± 3.5	25.1 ± 3.4
Quality of life (%)	73 ± 6	74 ± 7	74 ± 6

Materials and measurement systems in each experimental condition

Participants were instructed to walk on a 4.6-m treadmill. (GAITRite system; CIR Systems Inc., Clifton, NJ, USA) which had been demarcated with a system of references (RS) in the form of 12 equidistant marks placed in the center of the walkway.

Analysis was complemented with 3D photogammetry. Subjects were video recorded using two high-speed cameras (JVC GC-PX100BE) set at 200 Hz. Cameras were synchronized using a led. The concurrent validity of the GAITRite system and 3D photogammetry for stride time and length for the two experimental conditions was high ($ICC_{STRIDE\ TIME}$= 0.996 and 0.873 for normal walking and dual tasking, respectively; $ICC_{STRIDE\ LENGTH}$= 0.965 and 0.967 for normal walking and dual tasking, respectively).

As it was mentioned, there were two experimental conditions: a) *normal walking*, where participants were instructed to walk normally, and b) *performing a concurrent executive task while walking*, where participants were instructed to start walking when two traffic lights placed in front of them turned green simultaneously, and stop as fast as possible when the lights turned red. To force the use of selective attention, two traffic lights were installed on a tripod at the end of the treadmill at a 2-m distance from the subject, which geometric center was 1.70m high. Each traffic light was composed of three 25-led color lights 0.10 m in diameter. From top to bottom, lights were red, yellow, and green. The two traffic lights were connected to a computer with a programmed external card that controlled the activation of the six lights. Figure 1 displays a layout of the systems employed and their position on the treadmill.

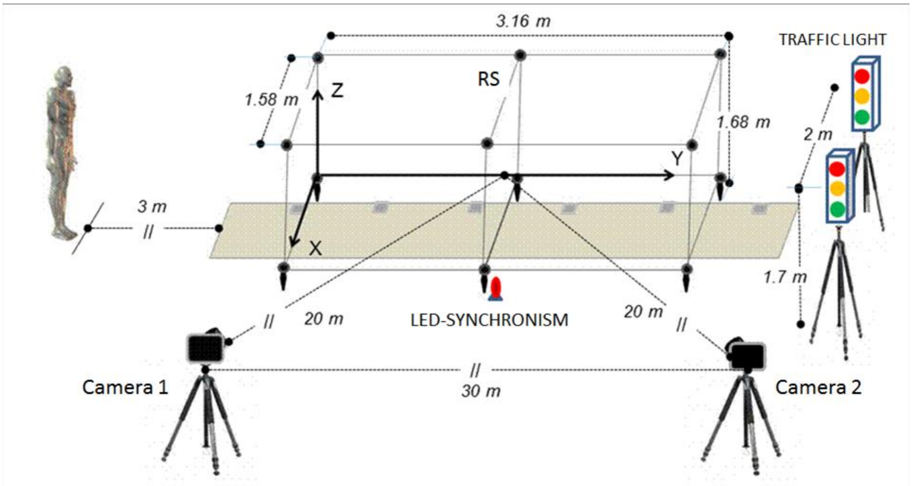

FIGURE 1: Layout of the measurement systems employed and their positions with respect to the treadmill.

Procedure

After WHOQOL-BREF questionnaire was filled out and anthropometric measures were obtained, the participants were instructed to walk under the two experimental conditions: In the *normal gait* condition, each participant started at a distance of three meters before getting on the treadmill, and walked normally at their usual speed. In the *dual-task* condition, participants had to start walking at their normal speed when the two traffic lights turned green simultaneously and stop when they turned red. While walking, lights randomly turned on and off. To familiarize with the systems, each subject performed three trials from which data were not collected. The experimental conditions were randomly presented to each participant. 3D photogammetry was analysed based on data from the valid trial which Gait Cycle Time (GCT) was the median of the five GCTs obtained in each experimental condition.

Data analysis

Cadence and gait variability were calculated using GAITRirte software. Data from 13 steps were extracted to estimate gait cadence (steps/minute) and variability in gait cycle time (GCT) and right and left step length in the two experimental conditions. Coefficients of variation were expressed as percentages of distance (Cv%).

The remaining parameters were calculated by 3D photogammetry using an adapted modular system designed *ad hoc* for gait analysis (Cyborg V. 3.0). Photogammetry was based on recordings of the reference system (RS) and of the gait cycle that was closest to the SR starting with the right foot. To this purpose, we designed a model of human body with 21 markers identifying 14 segments which masses and center of mass locations have been stablished by Zatsiorsky & Seluyanov (1985) and adapted by Leva (1996).

The coordinates of the 21 markers were estimated in three stages: a) Digitization of of the twelve markers that form the RS and the 21 markers that define the human model of the two cameras. To avoid interferences while walking, no markers were placed on participant's bodies, and digitization was performed manually at 50 Hz. b) Flat coordinates were interpolated at 100 Hz. Adjustment was performed by quintic splines with the level of smoothing set at 0.0001 (Wood & Jennings, 1979). c) Finally, the direct linear transformation was applied to calculate the 3D coordinates of the 21 points at successive intervals of 0.01s.

The space-time parameters employed for gait analysis were measured based on the spatial coordinates and the linear components of velocity of the center of mass (COM) were calculated from the first derivative of their respective spatial coordinates with respect to time using a quintic function.

Statistical analysis

The means and SD of each parameter in each experimental condition were calculated. Analysis of multivariate variance (ANOVA) of repeated measures was performed to calculate differences between means in the two experimental conditions (normal walking vs. dual-task walking). To assess test reliability, an analysis of variance of repeated measures was performed for all trials (five valid trials for each experimental condition). Gait Cycle Time (GCT) was the dependent variable. No significant differences were observed among trials in each experimental condition. The intraclass correlation coefficient was 0.992 ($p< 0.001$) for normal walking vs. 0.987 ($p< 0.001$) for dual-task walking.

RESULTS

Measures of central tendency in time parameters are shown in Table 2. The data obtained evidence that gait cycle time (GCT) tends to decrease when a concurrent executive task is performed ($p<0.05$). Thus, the mean cost to GCT due to dual tasking was -1.45±3.33 %. GCT analysis by gait phase reveals that dual-task cost is caused by differences between the means of the two single-support phases ($p<0.01$). In contrast, the means of the two double-support phases tended to increase in the dual-task condition. Nevertheless, differences between means in the two experimental conditions were not statistically significant. GCT variability (CV %) increased in the dual-task condition ($p<0.05$). No differences were observed in cadence between the two experimental conditions, which was calculated from 13 strides per experimental condition.

TABLE 2
Descriptive and inferential statistics for gait cycle time parameters in the two experimental conditions.

Variables	**Normal Gait**	**Gait & concurrent executive task**	**F**
Gait Cycle Time, GCT (s)	0.936 ± 0.075	0.922 ± 0.082	5.03*
Left-foot double support time (s)	0.110 ± 0.023	0.111 ± 0.023	0.02
Left-foot single support time (s)	0.354 ± 0.023	0.346 ± 0.024	7.27*
Right-foot double support time (s)	0.116 ± 0.022	0.118 ± 0.025	0.68
Right-foot single support time (s)	0.356 ± 0.026	0.349 ± 0.028	7.25*
Coefficient of Variance Gait Cycle Time (Cv%)	1.99 ± 1.03	2.88 ± 1.64	6.87*
Cadence (steps/minute)	130.8 ± 9.6	131.4 ± 11.4	0.12

** p< 0.05*

Table 3 displays descriptive and inferential statistics for stride length and their respective partial step lengths left and right, expressed as absolute values and percentage of the mean height of the two hips (greater trochanter) in anatomical position. Stride length and left/right-step length decreased significantly in the dual-task condition (p<0.001). The mean dual-task cost to stride length was -3.00±2.61 %. No significant differences were observed in step width between the two experimental conditions. No statistically significant differences were observed in swing width between the two experimental conditions. Finally, the variability observed in step length (Cv%) suggests that it increases when an executive task is performed while walking. Differences were more substantial between the mean left-step length (p<0.001) as compared to the mean right-step length (p<0.05).

TABLE 3
Descriptive and inferential statistics for spatial variables in the two experimental conditions.

Variables	Normal Gait	Gait & concurrent executive task	F
Stride Length, (m)	1.64 ± 0.13	1.60 ± 0.14	29.35***
Left Step Length (m)	0.82 ± 0.07	0.79 ± 0.08	21.79***
Left Step Length (%)	96.5 ± 7.9	93.4 ± 8.0	21.79***
Right Step Length (m)	0.83 ± 0.06	0.80 ± 0.07	16.14***
Right Step Length (%)	97.0 ± 6.4	94.3 ± 7.8	16.62***
Left Step Width (m)	0.07 ± 0.04	0.08 ± 0.03	1.73
Right Step Width (m)	0.08 ± 0.04	0.08 ± 0.04	1.19
Left Swing width (amplitude) (m)	0.06 ± 0.01	0.05 ± 0.01	1.51
Right Swing width (amplitude) (m)	0.06 ± 0.01	0.06 ± 0.01	1.60
Coefficient of Variance left Step Length (Cv%)	2.41 ± 1.16	4.48 ± 2.43	14.71***
Coefficient of Variance right Step Length (Cv%)	2.83 ± 1.37	3.84 ± 1.63	7.1*

**** p < 0.001; * p< 0.05*

Table 4 shows descriptive and inferential statistics on the mean velocity of the COM during the complete gait cycle and its phases. As displayed on the mean velocity of the COM tends to decrease when an executive task is performed while walking ($p<0.05$), which yields a DTC of -0.04±0.09 m/s. The same tendency was observed in mean velocity during the different phases of gait. Yet, differences in mean speed were only statistically significant during the right-leg double-support and single-support phase ($p<0.05$ and $p<0.01$, respectively). Descriptive and inferential statistics are also provided in Table 4 for the vertical displacement of the COM during left- and right-foot steps, without significant differences between means in the two experimental conditions. The same effect was noticed in the lateral displacement of the COM. These results suggest that the executive task proposed did not have any effect on the factors determining dynamic stability in gait.

TABLE 4
Descriptive and inferential statistics for the velocity of the center of gravity (CG) and the variables that determine the dynamic stability in the two experimental conditions.

Variables	Normal Gait	Gait & concurrent executive task	F
Velocity CG of the gait cycle (m/s)	2.01 ± 0.21	1.97 ± 0.24	4.58*
Velocity CG Left-foot double support (m/s)	2.13 ± 0.25	2.11 ± 0.28	0.36
Velocity CG Left-foot single support (m/s)	1.89 ± 0.20	1.87 ± 0.23	1.46
Velocity CG Right-foot double support (m/s)	2.15 ± 0.24	2.09 ± 0.26	5.07*
Velocity CG Right-foot single support (m/s)	1.87 ± 0.20	1.82 ± 0.22	9.97**
Displacement CGz left step	0.05 ± 0.01	0.05 ± 0.01	2.07
Displacement CGx left step	0.03 ± 0.01	0.03 ± 0.01	0.00
Displacement CGz right step	0.04 ± 0.01	0.04 ± 0.01	0.15
Displacement CGx right step	0.03 ± 0.01	0.03 ± 0.01	0.00

*** p < 0.01; * p< 0.05*

DISCUSSION

The results obtained confirm our hypothesis that the duration of the gait cycle tends to decrease when an executive task is performed concurrently. Of note, dual-tasking had a more dramatic effect on step length, which was significantly reduced in the two steps that determine stride length (p<0.001; see table 2). This reduction in stride length would presumably explain the mean 2% reduction in the velocity of displacement of the COM. These results are consistent with those reported in previous studies assessing the dual-task cost (DTC) to gait in people with disorders or elderly people (Al-Yahya et al., 2011; Belghali et al., 2017; Gutiérrez-Cruz et al., 20016; Kelly, Eusterbrock, & Shumway-Cook, 2012; Rochester, Galna, Lord, & Burn, 2014). It should be taken into account that, in this study, data were obtained from healthy adults without any motor and/or cognitive disorder, which led us to conclude that the DTC to gait performance of executive tasks requiring gait inhibition is not only caused by neuromotor or sensory deficits.

The results obtained also suggest that the executive discrimination task proposed had no effects on dynamic stability-related factors. Briefly, no statistically significant differences were observed in step width, swing width, and vertical and lateral displacement of the COM between the two experimental conditions (see Tables 3 and 4). These results are in line with those reported in previous studies, which suggest that only relatively complex concurrent tasks affect postural control in healthy young adults. In contrast, elderly adults or subjects with motor or cognitive impairment are more affected by dual tasking (Ebersbach, Dimitrijevic, & Poewe, 1995; Gutiérrez-Cruz et al., 2016; Lajoie et al., 1993;1996; Nording et al., 2010; Rankin, Woollacott, Shumway-Cook, & Brown, 2000).

The DTC to some gait performance factors in people with full motor and cognitive function is supported by the two-visual-stream (Goodale & Westwood, 2004) and strategic facilitation of response inhibition. There must be a basic level of DTC to some gait performance factors that could be related to the type and complexity of the concurrent task performed and conditioned by individual capabilities. A relevant factor determining DTC to gait performance seems to be vertebral, subcortical or cortical structure deficits (Woollacott & Shumway-Cood, 2002; Al-Yahya et al., 2011) The results of this study suggest that to assess DTC it is necessary to calculate the differential DTC in subjects with limited motor and/or cognitive capacity as compared to healthy individuals.

A detailed analysis of the effects of the concurrent task proposed on the different phases of gait evidence that DTC to the different gait phases is variable. The reason might be that each phase involves different motor structures (Abbud & DeMont, 2009; Lajoie et al., 1993). In our study, dual tasking only had a significant impact on single-support time for the two legs ($p<0.05$; see Table 1). The reasons might be that maintaining dynamic balance requires an intense use of resources added to the fact that step length decreased significantly but swing width remained the same (see Table 3). Although single-support time was lower in dual-task conditions, it is the substantial reduction in stride length what caused a decrease in the velocity of the COM. Significant differences were only observed during right-foot double-support and single-support phases ($p<0.05$ and $p<0.01$, respectively –see Table 3-). This phenomenon can only be explained by the different roles that each leg plays in terms of limb dominance. In fact, the dominant limb in 25 of the 28 participants was the right leg, which is an incidental finding, as this factor was not within the scope of this study.

The analysis of data from 13 steps performed in each experimental condition revealed the impact of dual tasking on gait cycle time and step length (see tables 2 and 3), which is consistent with the results obtained by Nascimbeni, et al. (2015) who reported changes in gait performance caused by dual tasking in elderly people with and without mild cognitive impairment. However, the mean cadence was not altered by dual-tasking, probably due to the negligible time differences observed between the two experimental conditions, added to the increased time variability of the 13 steps analyzed in dual-task conditions. Of note, these data are in conflict with the conclusions drawn by Al-Yahya et al. (2011), who reported a reduction in gait cadence in dual task conditions both, in healthy subjects and in subjects with neurological disorders.

Conclusions

The performance of discrimination and decision-making tasks while walking in young adults without motor and/or cognitive disorders tends to reduce single-support time of the two feet. The decreased step length would explain the 2% reduction of velocity of displacement of the COM. Step time and length variabilities increased with dual tasking.

The results obtained confirm that performing an executive task while walking has a cost to some gait performance factors in healthy subjects without motor and/or cognitive disorders. This suggests that a dual task cost (DTC) differential should be used in people with motor and/or cognitive disorders as compared to healthy subjects. Investigating other types of concurrent tasks with different levels of complexity is a promising avenue for future research.

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