

Optimizing Exercise Performance With a Continuously Paced Shuttle Walk Test for Patients With Chronic Obstructive Pulmonary Disease

Fernanda W. Rosa, Aquiles Camelier, Anamaria Mayer, and José R. Jardim

Pulmonary Division/Rehabilitation Center, Federal University of São Paulo, Brazil.

BACKGROUND: A continuously paced shuttle walk test (SWTp) was developed to test the hypothesis that speed and rhythm could be more optimally imposed by an easier-to-follow sound stimulus at every step. The objective of this study was to assess the reproducibility of the SWTp and to compare the performance of patients with chronic obstructive pulmonary disease (COPD) on the conventional and optimally paced forms of the test.

PATIENTS AND METHODS: The walk test results of 24 COPD patients were studied. All patients completed 2 SWTp sessions and a conventional SWT in random order, after an initial practice test for each. A portable device was used to measure peak oxygen uptake (VO_2) in 6 patients.

RESULTS: The intraclass correlation coefficient (Cronbach's α) was 0.95 for the STWp. The Pearson correlation coefficient between distance walked and peak VO_2 in the SWTp was 0.86 ($P < .02$). Better performance was achieved during the SWTp (peak VO_2 , 3.30 mL/kg/min; $P < .01$; distance walked, 32 m, $P < .001$) than during the conventional SWT. The SWTp showed excellent reproducibility.

CONCLUSIONS: COPD patients can achieve better performance with the stimuli provided in the SWTp than in the conventional SWT.

Key words: *Pulmonary disease chronic, obstructive. Exercise test. Physical activity. Reproducibility. Rehabilitation.*

Optimización de la capacidad de realización de ejercicio físico mediante una prueba de la lanzadera por tramos con estimulación auditiva continua en pacientes con EPOC

OBJETIVO: Se ha desarrollado una prueba de lanzadera por tramos (SWT, de *shuttle walk test*) con estimulación auditiva continua (SWTp, *paced shuttle walk test*) para comprobar la hipótesis de que es posible que los pacientes consigan una velocidad y un ritmo mejores mediante la aplicación de un estímulo sonoro, de seguimiento más fácil por ellos y correspondiente a cada paso que realizan en la prueba. El objetivo de este estudio ha sido evaluar la reproducibilidad de la SWTp y comparar el rendimiento de los pacientes con enfermedad pulmonar obstructiva crónica (EPOC) en la SWT con estimulación sonora convencional y en la SWTp con estimulación sonora óptima.

PACIENTES Y MÉTODOS: Se han evaluado los resultados obtenidos por 24 pacientes con EPOC en la prueba de ejercicio de caminar. Todos los pacientes completaron 2 sesiones de SWTp y una sesión de SWT convencional, tras su distribución aleatoria a los grupos y después de efectuar una sesión inicial de práctica con cada una de las pruebas. Se utilizó un dispositivo portátil para determinar el consumo de oxígeno (VO_2) máximo en 6 pacientes.

RESULTADOS: El coeficiente de correlación intraclass (alfa de Cronbach) fue de 0,95 para la STWp. El coeficiente de correlación de Pearson entre la distancia recorrida en la prueba y el VO_2 máximo respecto a la SWTp fue de 0,86 ($p < 0,02$). Se consiguió un rendimiento mejor durante la SWTp (VO_2 máximo de 3,30 ml/kg/min, $p < 0,01$; distancia recorrida de 32 m, $p < 0,001$), en comparación con la SWT convencional. La SWTp se acompañó de una reproducibilidad excelente.

CONCLUSIONES: Los pacientes con EPOC pueden alcanzar un rendimiento mayor con el estímulo auditivo proporcionado en la SWTp que con el correspondiente a la SWT.

Palabras clave: *Enfermedad pulmonar obstructiva crónica. Prueba de esfuerzo. Actividad física. Reproducibilidad. Rehabilitación.*

Correspondence: Dr. Fernanda Warken Rosa.
Rua Manoel Andrade, 201 – Ap 401.
Cond. Pituba Ville. Pituba. Salvador. Brazil.
E-mail: fwrosa@yahoo.com.br

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Introduction

Maximum incremental cycloergometer or treadmill tests, with measurement of peak or maximum oxygen uptake (peak VO_2 or $\text{VO}_{2\text{max}}$), anaerobic threshold and other parameters, can be used for the assessment of

functional capacity and limitations or the prescription of exercise for COPD patients.¹⁻³ However, the direct measurement of such parameters requires costly equipment as well as highly trained personnel.^{4,5} Hence, certain easy-to-perform field tests have been developed to evaluate patients with COPD. Examples are the step test⁶ and the shuttle walk test (SWT).⁷

The SWT, which uses walking as the main activity, is simple and reproducible, requiring no more than one practice session.^{7,8} It is performed with an external sound stimulus to indicate when a subject should be changing direction in an oval circuit and another sound to mark when pace should be increased at the end of a series of shuttles at a particular level of walking. The SWT has been used for exercise evaluation, prescription of therapy, and training, and as a useful outcome measure for evaluating interventions in COPD patients.^{7,9-12} High correlations have been found between the distance walked in the SWT and both peak VO_2 ($r=0.81$) and $\text{VO}_{2\text{max}}$ obtained in a conventional treadmill test ($r=0.88$),¹³ but the correlation is slightly lower in comparisons with a maximum cycloergometer test ($r=0.71$).³ A good correlation has also been found between $\text{VO}_{2\text{max}}$ and the distance walked in a SWT in patients with congestive heart failure ($r=0.83$)^{14,15} or asthma ($r=0.84$)¹⁶ and in children with cystic fibrosis ($r=0.95$).^{17,18} When the SWT has been used to detect response to a pulmonary rehabilitation program in COPD patients, improvements in the distance walked have ranged from 25 m to 88 m.^{19,20}

However, the external sound stimulus provided in the SWT may be considered its weak point. For untrained patients, it may be hard to adjust pace to maintain or change walking speed at each level of the test. This possible influence of the external sound stimulus on a patient's SWT performance has not yet been studied to our knowledge. In order to improve optimal administration of the SWT and perhaps make it easier to carry out, we modified the sound stimulus with the expectation that step-by-step pacing would better guide the patient's adjustment to the speed required during each shuttle. Thus, the objective of this study was to investigate whether the modified SWT, called the optimally paced SWT (SWTp), is reproducible and effective in comparison with the conventional SWT in COPD patients.

Methods

Twenty-four patients with COPD according to criteria of the Global Initiative on Obstructive Lung Disease (GOLD)²¹ were recruited consecutively from among those referred to our university outpatient clinic. The sample size provided 80% power to detect a 10-m difference (SD, 11 m),^{19,20} assuming an α error of .05. The inclusion criteria were a PaO_2 of at least 55 mm Hg and/or oxygen saturation by pulse oximetry (SpO_2) of at least 88% (at rest, breathing room air), at least 6 weeks of clinical stability prior to enrollment, and the ability to walk. Patients with SpO_2 of 80% or less during exercise, unstable concomitant disease, or any other formal contraindication to performing the tests were excluded. Spirometry was performed on all patients according to

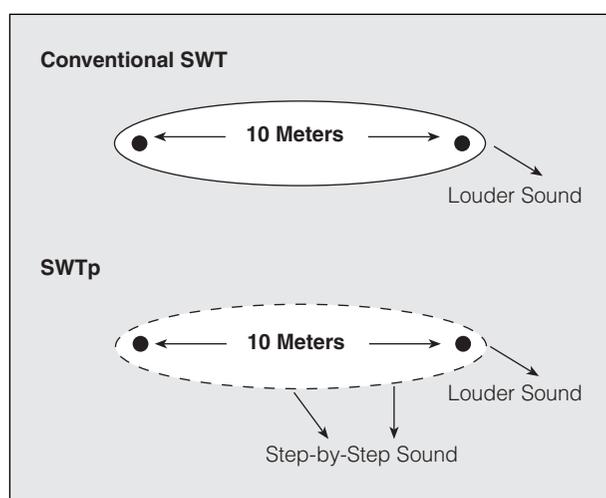


Figure 1. Sound stimuli for the conventional and optimally paced shuttle walk tests (SWT and SWTp, respectively).

American Thoracic Society criteria,²² using a KoKo spirometer (PDS Instrumentation, Louisville, Colorado, USA). All patients also underwent arterial blood gas analysis. The body mass index (BMI) was calculated as the ratio of weight in kilograms to height in meters squared.

Test Protocol

The conventional SWT as described by Singh and colleagues⁷ and the SWTp as described below were performed on the same day (in a random order) with a minimum interval between them of 30 minutes or as long as it took for cardiovascular and respiratory variables to return to resting values. Another SWTp was performed a day later. Direct measurements of peak VO_2 , CO_2 production (VCO_2), minute ventilation (V_E), heart rate (HR), oxygen pulse (VO_2/HR), and breathing frequency (f_R) were made with a portable telemetric system (K4b², COSMED, Rome, Italy) in a randomly chosen subset of 6 patients who performed both a conventional SWT and the first SWTp, to evaluate the metabolic differences during the 2 tests. Double product was also calculated. Dyspnea and sensation of leg effort were assessed at rest and after each test on a modified Borg scale.

The modified sound signal that was developed for the SWTp was intended to provide a beep to correspond to each step to be taken, in addition to the louder sound signal indicating the change in direction at the far end of the shuttle after the subject had passed the cone (Figure 1). To develop the pacing sound beeps for the new SWTp, given that a step is influenced by height and lower limb length, 20 healthy volunteers were studied in 2 groups characterized by height. Thus, subjects were less than 1.60 m tall or 1.60 m or taller. They initially walked on a treadmill following the conventional set of SWT speeds. The standardized time intervals between the louder beep sounds, which signal a shuttle turn in the conventional SWT, were divided by the mean number of steps adopted for each speed level in the 2 groups. Then, each step time interval between the conventional SWT beeps (for turning at the end of a shuttle) was calculated. Thus, the original shuttle time intervals and speeds remained the same as in the conventional SWT, even though patients of different heights heard a different number of beeps, corresponding to steps to take, on the SWTp (Table 1).

A practice test was performed by all patients before each test type in order to explain the differences between the 2 modalities of sound stimulus and to exclude a learning effect in the study.

The protocol was approved by the university ethics committee and written informed consent was obtained from all patients.

Statistical Analysis

The results are presented as means (SD). The intraclass correlation coefficient (Cronbach's α) was calculated in order to estimate the reproducibility of the tests.²³ The paired *t* test was used to analyze differences between variables recorded during the 2 types of walk test (SWT and SWTp). The Pearson correlation coefficient (*r*) was calculated to study the association between the distances walked in the tests. Parametric tests were justified by a kurtosis analysis. Individual variability was analyzed using a plot as proposed by Bland and Altman.²⁴ The level of statistical significance was set at *P* less than .05. Statistical analysis was performed with the SPSS software, version 10.

Results

The demographic and lung function data of the 24 COPD patients (17 men) are shown in Table 2; the mean age was 67.8 (7.5) years (range, 55–84 years), and the mean BMI, 24.2 (4.2) kg/m². According to the GOLD criteria, 2 patients (8.3%) had a mild form of COPD (stage I); 7 patients (29.2%), moderate COPD (stage II); 12 (50%), severe COPD (stage III); and 3, very severe disease (stage IV). Two patients (8.3%) were hypercapnic (PaCO₂>45 mm Hg).

There were no significant differences between distances walked, HR, *f_R*, or other variables measured during the 2 SWTp sessions (data not shown). The intraclass correlation coefficient (α) for distance walked was 0.95 (95% confidence interval [CI], 0.89–0.95; *P*<.0001). For other variables, α levels between the 2 SWTp sessions are shown in Table 3.

The mean distances walked in the 2 SWTp sessions were significantly greater than the distance walked in the conventional SWT (mean distance walked in the first SWTp, 334.9 m; in the second SWTp, 339.1 m; in the conventional SWT, 307.0 m; *P*<.03 and .05, respectively). The individual differences in distance walked in the 2 SWTp sessions and between the first SWTp and the SWT are shown in Figures 2 and 3, respectively). The mean differences between each of the 2 SWTp sessions and the conventional SWT and the SWTp were evaluated for 4 variables. Between the first SWTp and the SWT the differences were 27.8 (11.9) m for distance walked (*P*=.03); 1.5 (0.3) for dyspnea (*P*=.0001); -0.7 (0.5) for sensation of leg effort (*P*=.17); and 8.5 (2.2) beats/min for maximum HR (*P*=.08). The mean differences between the second SWTp and the conventional SWT for the same variables were 32.2 (10.3) m for distance walked (*P*=.005); 1 (0.4) for dyspnea (*P*=.03); 0.3 (0.3) for sensation of leg effort (*P*=.4); and 6.4 (1.9) beats/min for maximum HR (*P*=.002).

The demographic and lung function characteristics of the subset of 6 patients in whom peak VO₂ was

TABLE 1 Shuttle Walking Test Speeds at 12 Levels and Number of Beeps Corresponding to Steps in the Continuously Paced Test by Patient Height*

Levels	Walking Speed, m/s	No. of Beeps (Steps)	
		Height <160 cm	Height ≥160 cm
1	0.50	27	21
2	0.67	24	20
3	0.84	21	19
4	1.01	20	17
5	1.18	18	16
6	1.35	17	15
7	1.52	16	14
8	1.69	16	14
9	1.86	15	13
10	2.03	15	13
11	2.20	14	12
12	2.37	13	12

TABLE 2 Lung Function and Other Characteristics of the 24 COPD Patients*

Variables	Mean (SD)
Age, y	67.8 (7.5)
BMI, kg/m ²	24.2 (4.2)
FVC, % [†]	80.9 (21.0)
FEV ₁ , % [†]	48.6 (21.0)
FEV ₁ /FVC, % [†]	45.6 (9.8)
MVV, L/min	48.5 (23.4)
PaO ₂ , mm Hg	68.1 (8.5)
PaCO ₂ , mm Hg	38.9 (4.8)
SaO ₂ , %	93.2 (2.4)
BD	7.5 (2.1)

*COPD indicates chronic obstructive pulmonary disease; BMI, body mass index; FVC, forced vital capacity; FEV₁, forced expiratory volume in 1 second; MVV, maximum voluntary ventilation; SaO₂, oxygen saturation in arterial blood; BD, baseline dyspnea on a modified Borg scale.
[†]Postbronchodilator variables.

TABLE 3 Intraclass Correlation Coefficients (Cronbach's α) and 95% Confidence Interval of Maximum Performance Results Obtained in the 2 SWTp Sessions*

VVariable	α	95% CI	<i>P</i>
Distance, m	0.95	0.89–0.95	<.00001
HR, beats/min	0.94	0.75–0.95	<.00001
<i>f_R</i> , breaths/min	0.89	0.60–0.91	<.00001
SBP, mm Hg	0.86	0.50–0.88	<.00001
DBP, mm Hg	0.87	0.54–0.89	<.00001
Double product	0.93	0.72–0.94	<.00001
SpO ₂ , %	0.98	0.90–0.98	<.00001
Dyspnea, Borg scale	0.77	0.31–0.82	<.00001
Leg effort, Borg scale	0.78	0.33–0.83	<.00001

*CI indicates confidence interval; HR, heart rate; *f_R*, breathing frequency; SBP, systolic blood pressure; DBP, diastolic blood pressure; SpO₂, oxygen saturation by pulse oximetry.

compared between the SWT and SWTp did not differ from those of the whole sample (data not shown). The peak VO₂ was significantly higher (by 3.30 mL/kg/min, or 14% more) in the SWTp (23.7 [4.9] mL/kg/min in

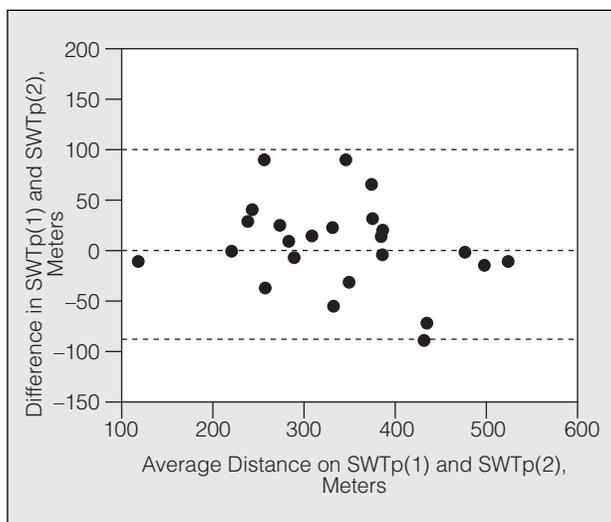


Figure 2. Individual variability in the distance walked during the first and second optimally paced shuttle walk test (SWTp). The horizontal dotted lines show the mean \pm 1.96 SD: 4.3 \pm 87.5.

the SWTp vs 20.4 [6.9] mL/kg/min in the conventional SWT; $P < .05$). The correlation between peak VO_2 and the distance walked was very good in both forms of SWT ($r = 0.90$, $P < .02$, in the conventional test; and $r = 0.86$, $P < .03$, in the SWTp) as displayed in Figure 4.

Discussion

The SWT is one of the low-cost alternatives able to evaluate exercise limitation in COPD patients.⁷ In this test, the change in walking speed is suggested by a single-beep sound stimulus marking when a subject should reach the cones and change directions and by a triple beep indicating the change to a higher level of walking, but this information may be very inadequate

for telling the patient what pace to follow in walking. In order to avoid delays during the test caused by the difficulty of guessing the right speed to follow, we developed a step-by-step sound stimulus, to help the subject maintain a rhythm in pacing. At higher speeds in particular, it was thought that a stimulus for every step would provide a better pacing guide. Despite the widespread use of the 6-minute walk test in COPD patients, the SWT remains an alternative and it is important to evaluate all the field test alternatives in these patients, prioritizing tests that are not expensive to administer. The SWT is such a test, though it has been used less often, especially in rehabilitation centers in Latin American and on the Iberian Peninsula.^{25,26}

The SWTp is highly reproducible, and no more than a single practice session is needed for a subject to learn to carry it out.^{7,8,15,18,27} Very good intraclass correlation has been shown for both COPD patients ($\alpha = 0.88$)⁸ and adults with cystic fibrosis ($\alpha = 0.99$).¹⁸ We tested the reproducibility of a new version with an optimally paced sound stimulus, the SWTp, by comparing 2 test sessions in which this new modality was applied, and found an α level of 0.95. Good reproducibility was also achieved in both the cardiovascular (HR, systolic and diastolic blood pressures) and respiratory (f_R) parameters, as well as for dyspnea and leg effort sensation (Borg scale), suggesting that the exercise load was similar in the tests. According to these findings, we suggest that a single practice session before the SWTp is adequate. We believe that the learning effect is somewhat eased by the external sound stimulus guiding the steps.

Differences between the two shuttle test modalities were analyzed by comparing the results of the single SWT and the 2 SWTp sessions. Only a 4-m difference between the first and second SWTp was observed, but the difference between the SWT and the SWTp was 28 m to 32 m (approximately 3 shuttles), favoring the new

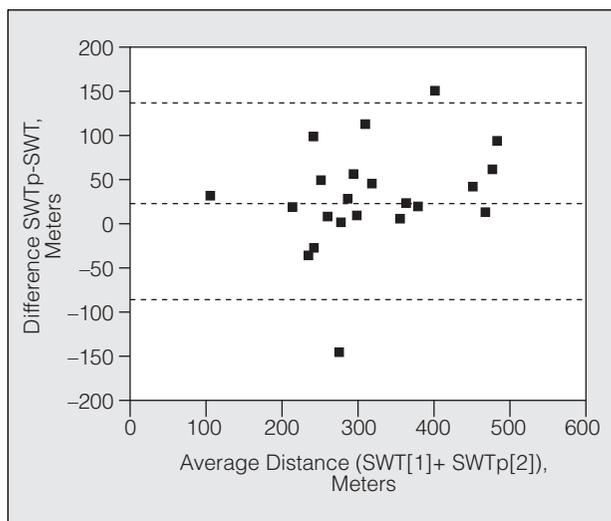


Figure 3. Individual variability in the distance walked on the conventional shuttle walk test (SWT) and the first optimally paced test (SWTp). The horizontal dotted lines show the mean \pm 1.96; SD, 27.8 \pm 113.1.

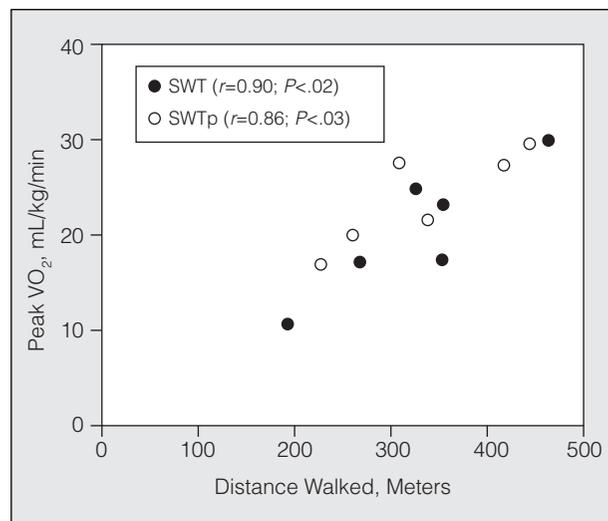


Figure 4. Linear correlations (Pearson) between peak VO_2 (mL/kg/min) and distance walked in the conventional shuttle walk test (SWT) and the optimally paced modality (SWTp) in 6 COPD patients.

approach ($P < .01$). In fact, the differences obtained in a randomized trial of a pulmonary rehabilitation program ranged from 2 m to 10 m in the control group, and this might be assumed to be attributable to a learning effect.²⁷ As the learning effect was mitigated in the present study through a practice test and randomization of the order of the tests, we can assume that the mean increase in the distance walked during the 2 SWTp sessions (30 m) in comparison with the conventional test was due to the modified sound stimulus guiding each step. The better performance in the SWTp could be explained by better understanding of how the steps should be taken in order to reach the cones at the ends of the course, suggesting better mechanical efficiency. In both first and second SWTp sessions, all patients completed the eighth level of the test, whereas they could go no higher than the seventh level during the conventional SWT. No patient in either test modality reached the final level (12th), consistent with reports in the literature.⁷ The 30-m difference between the two tests might nonetheless be considered a clinically nonsignificant difference, as clinical significance has been suggested to start at 45 m.²⁸ This suggests that the SWTp is a reproducible alternative to other exercise walk tests and that it possibly demands a bit more of patients than the SWT.

The SWT is an incremental test, with the speed increasing at intervals of 1 minute.⁷ It has been demonstrated that a high metabolic demand is imposed by the SWT and that there is a good positive correlation between the distance walked and peak VO_2 in COPD patients on both treadmill tests ($r=0.88$)¹³ and on cycloergometer tests ($r=0.71$).³ A good correlation coefficient correlation (0.81) between the peak VO_2 measured by a portable device during the SWT and the distance walked by COPD patients has been reported.¹³ When we analyzed the peak VO_2 during the SWTp and the conventional SWT in 6 COPD patients, with measurements made by a portable telemetric device weighing 800 g, the results showed excellent correlation with SWTp distance walked ($r=0.86$; $P < .03$). That level of correlation was similar to the results for the SWT in this study ($r=0.90$; $P < .02$) and to the findings of Singh and coworkers¹³ for the same comparison. On the average, the peak VO_2 in the SWTp (23.7 mL/kg/min) was higher than in the conventional SWT (20.4 mL/kg/min; $P=.01$). This was an expected finding once the patients walked a longer distance in the SWTp. It is possible, however, that the good correlations of the SWT with maximum incremental exercise tests (on a treadmill or a cycloergometer)—even better than the correlation between the SWT and the 6-minute walk test—possibly reflect different aspects of exercise adaptation. The 6-minute walk test is in widespread use and possibly measures a functional component of tolerance or endurance not evaluated by the SWT.

The first limitation of this study is that no formal opinions of the patients were collected to evaluate whether the modified sound stimulus helped them to perform the test. Another limitation is the lack of comparison between the SWTp and a maximum effort

treadmill or cycloergometer test. These limitations restrict full extrapolation of the results.

In conclusion, COPD patients seem able to achieve a slightly higher peak VO_2 and walk a slightly longer distance with the modified sound stimulus that guides pacing in the SWTp in comparison with the conventional SWT. The SWTp can be considered as a valid alternative for evaluating exercise capacity when walk tests are being considered for COPD patients.

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WARKEN ROSA F ET AL. OPTIMIZING EXERCISE PERFORMANCE WITH A CONTINUOUSLY PACED SHUTTLE WALK TEST FOR PATIENTS WITH CHRONIC OBSTRUCTIVE PULMONARY DISEASE

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