London2PC: Versión computarizada de una tarea para evaluar la planeación

London2PC: Computerized version of a task to evaluate planning

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Resumen

La tarea de la Torre de Londres ha sido reportada como una de las tareas más utilizadas para evaluar la planeación. El estudio de las funciones ejecutivas requiere herramientas que permitan minimizar los errores de aplicación y calificación, al tiempo que aseguren una mayor precisión y practicidad. Este artículo se centra en el desarrollo y descripción técnica de London2PC, una versión computarizada mejorada de esta tarea, diseñada con el objetivo de eliminar errores de implementación, facilitar la accesibilidad y permitir aplicaciones remotas. Además, esta versión computarizada incluye una nueva opción que permite separar una fase de planeación de la fase de ejecución. London2PC requiere recursos computacionales mínimos para su ejecución, es de fácil acceso y genera resultados con alta precisión y especificidad en formato ASCII; es una herramienta práctica y eficiente para la evaluación de la planeación. Es adecuada para su uso tanto en investigación básica como aplicada, en poblaciones sanas y con patologías. London2PC está disponible de forma gratuita mediante solicitud formal a los autores.

Palabras clave: Función ejecutiva, planificación, tarea informatizada, evaluación, Torre de Londres.

Abstract

The Tower of London task has been reported as one of the most frequently used tasks to evaluate planning. Studying executive functions requires tools that make it possible to minimize application and qualification errors while ensuring greater precision and practicality. This article focuses on the development and technical description of London2PC, an improved computerized version of this task designed with the aim of eliminating implementation errors, facilitating accessibility and remote applications. In addition, this computerized version includes a new option that makes it possible to separate a planning phase from the execution phase. London2PC requires minimal computational resources for its execution, is of easy access, and generates results with high precision and specificity in ASCII format; it is a practical, efficient tool for evaluating planning. While suitable for use in basic and applied research, both healthy and pathologies populations. London2PC is available free of charge from the authors by formal request.

Keywords: Executive function, planning, computerized task, evaluation, tower of London.

Introduction

Based on the Tower of Hanoi task, the Tower of London was designed by Shallice in 1982 (Shallice, 1982) with the aim of designing a tool that would make it possible to measure planning skills with gradual degrees of difficulty. Since its creation, this test has been used to evaluate the planning process (Debelak *et al*., 2016) in clinical neuropsychological assessments and as a tool in neuroscientific research.

The Tower of London measures executive functions, especially those related to planning, understood as the ability to choose and organize our future behavior (Hayes-Roth & Hayes-Roth, 1979). Planning is present in many moments of our daily lives; for example, we plan our route to school or work, and our dinners, celebrations, and professions, both everyday activities and of great importance. Beyond this executive process, the Tower of London has been used to evaluate other cognitive functions that can affect task performance, including working memory, inhibition, and fluid intelligence (D'Antuono *et al*., 2017), and to evaluate problem-solving, by virtue of the fact that it includes initial and goal states (Owen *et al*., 1990).

Executing the Tower of London involves various subprocesses, such as attentional control to maintain the initial and goal states and working memory during the monitoring of the motion sequence until the target goal is achieved. This multiple processing involves the functioning of several brain structures, including regions of the prefrontal cortex (Berg & Byrd, 2002) and the parietal and occipital posterior cortices (Baker *et al*., 1996).

The prefrontal cortex is a main cortical area implicated in the modulation of cognitive processes, so it has been strongly related to execution of the Tower of London. The participation of this cortical area has been elucidated in several studies using repetitive transcranial magnetic stimulation (Srovnalova *et al*., 2012) and functional magnetic resonance (Cazalis *et al*., 2003; Wagner *et al*., 2006), and in patients with brain lesions (Yochim *et al*., 2009). It continues to be widely used in clinical, school, and research settings to detect possible affectations of the prefrontal cortex and cognitive planning skills in both healthy subjects and those with pathologies.

The classic Tower of London task consists of three perforated colored beads that can be moved along three pegs of descending lengths that can hold 3, 2, and 1 beads, respectively. The aim of the task is to reach a target arrangement of the beads starting out from an initial, given, position. During this process, the subject evaluated is allowed to see the target model on an identical tower structure managed by the examiner. In the classic version the maximum response time is set at two minutes for each individual goal (Shallice, 1982).

Subsequent to Shallice's version, an update was proposed to increase the applicability of the test, and the Tower of London-Drexel was developed, first for use with children (Culbertson & Zillmer, 1988, 1998), then adapted for older populations (Culbertson & Zillmer, 1999). Changes included eliminating repeated trials to maintain novelty across the items presented, decreasing time-on-task, and introducing 6- and 7-move tests to raise the instrument's "ceiling".

The set of goals on this computerized version of the Tower of London consists of 10 trials of increasing difficulty with a limit on the number of moves allowed, from 3-7 (the minimum number of moves allowed increases with the level of difficulty). To perform the task, the examiner tells the subject that they must obey two rules (Culbertson & Zillmer, 1999):

1. Only one bead can be moved at a time.
2. Only the number of beads that fit on each peg can be placed there.

The examiner evaluates subjects' execution by recording the number of moves, the number of rule violations, and the time required to solve each pattern. Performance is evaluated by quantitative variables (Culbertson & Zillmer, 1999):

a) Total number of moves to achieve the goal.

b) Move score: the number of the subject's moves minus the minimum number of moves assigned.

c) Latency to first move: the time the subject takes to move the first bead.

d) Execution time: the time elapsed from the move of the first bead to task completion.

e) Total execution time: sum of the latency to first move plus execution time.

f) Number of violations of rule 1.

g) Number of violations of rule 2.

h) Number of time violations: when the subject does not complete the problem within two minutes.

Method

London2PC: Updated Computerized Version of Tower of London

As mentioned above, the Tower of London has been used in many types of research (Albert & Steinberg, 2011; Phillips, 1999; Phillips *et al*., 2001), but its application has been affected by inaccuracies on the part of evaluators who must simultaneously measure each subject's execution times and record the number of moves. Striving to eliminate such inaccuracies, a first computerized version of the test was developed, called LondonPC. Our aims in elaborating this new version –London2PC– were to

(i) preserve the characteristics of the first version; (ii) implement a new function; and (iii) facilitate accessibility to the software for remote applications. As in the prior version, this one is based on the execution rules of the Tower of London-Drexel task, but it minimizes the limitations on application and the scoring errors associated with the physical version. Unlike the original test and the commercial version by Culbertson & Zillmer (Culbertson & Zillmer, 1999), which provided a maximum of 10 goals, the London2PC program offers as many as 35 goals. These possible combinations allow examiners to present trial arrangements distinct to those proposed by Shallice, Culbertson, and Zillmer (Culbertson & Zillmer, 1999; Shallice, 1982) and to adjust them to fit specific research projects. London2PC also permits changing the time limit configured for each trial.

Like the physical version, London2PC proposes a series of trials (goals or targets) in which subjects start from an initial position (illustrated in Figure 1) and move the beads to duplicate a new arrangement. Subjects can see the target image throughout the exercise. Each trial ends when one of the following three conditions is met: a) the goal is reached; b) the assigned time runs out (usually 2 minutes); or c) the maximum number of moves allowed is reached without reaching the goal. Figure 2 shows the 36 valid positions of the beads on the pegs. One of these is given as the starting position (here, set to position #7), while any one of the other 35 can be set as the target position.

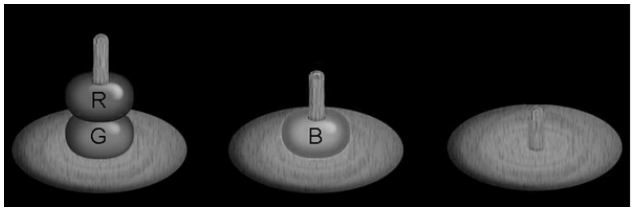

Figure 1. Initial position in each trial. Letters on the image is to indicate the color of each bead.
Note: R: red, G: green, B: blue.

As mentioned, London2PC was elaborated to provide up to 35 goals per session. Table 1 shows all possible goals, ordered according to the number assigned in the program (see Figure 2). Goals that require fewer moves can be used for demonstration purposes or to test whether the person being evaluated understands the rules.

In addition to the classic application in which subjects are shown initial and target positions, this computerized version of the Tower of London (London2PC) includes a new option that makes it possible to separate a planning phase from the execution phase. This option (called the "planning-previous mode") allows subjects to plan a first quantification of the moves; that is, they can see the positions but before beginning to move the beads, must plan and select (using the keyboard or on the screen) the minimum number of moves required to reach the goal (from 1-8, or over 8). This option is accompanied by the well-known execution step to reach the goal by making the corresponding moves (classic mode). London2PC offers both modes, classic and novel.

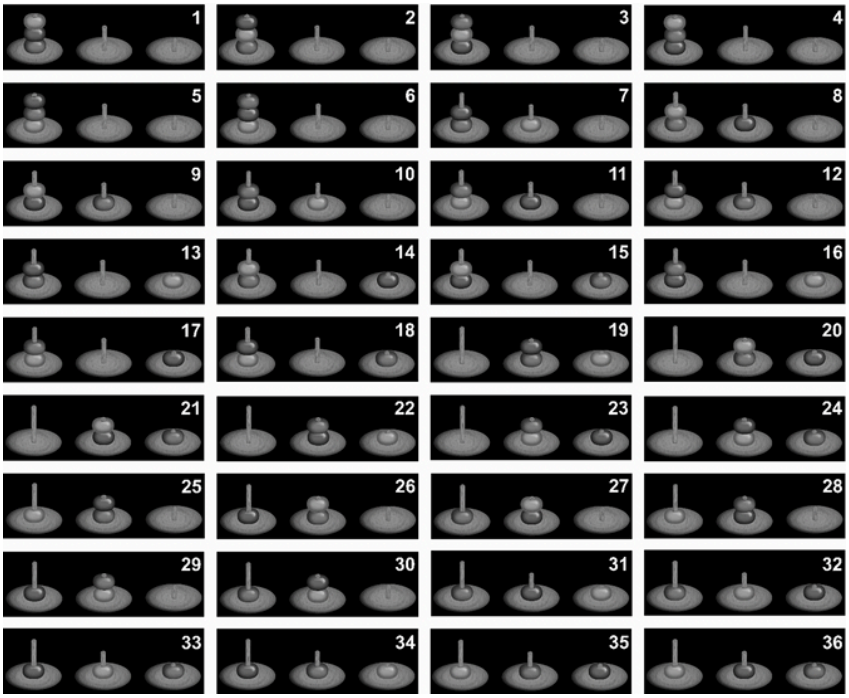

Figure 2. The 36 possible positions of London2PC.

Table 1. List of the 36 valid positions, 35 of which can be goal positions.

Goal number	Number of movements	Goal number	Number of movements
1	1	19	7
2	3	20	7
3	5	21	4
4	5	22	3
5	6	23	2
6	7	24	2
7	0	25	8
8	3	26	6
9	5	27	3
10	4	28	4
11	5	29	3
12	7	30	1
13	1	31	2
14	2	32	1
15	4	33	3
16	5	34	6
17	6	35	7
18	6	36	5

Note: The minimum number of moves to reach each goal is shown, starting from position 7.

Program Description

The program is easy to use. On the initial screen, the evaluator can select either the classic mode (1), or the planning-previous mode (2), set the minimum number of moves, and select the maximum time, in seconds, allowed to reach each goal (default time = 120 seconds). The button "Choose file for results" must be pressed to select a folder, assign a name to the results file, and select a text file that contains the goals that will be used in the session (called "Choose sequence file", see Figure 3).

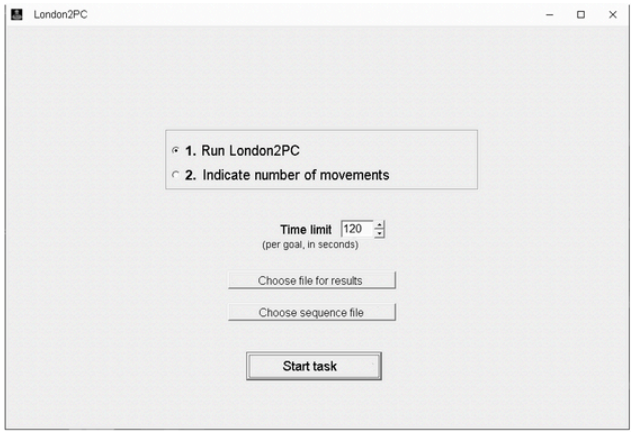

Figure 3. Initial software screen where the task is configured in the planning-previous mode.

After this configuration step, pressing the "Start task" button will show the second screen (Figure 4). It explains the instructions for executing the task. There is no time limit for subjects to read the instructions. Once they understand, they press one of the number keys assigned to the posts (1-9) to begin the trials. In the planning-previous mode, each trial presents two screens. In the first, shown in Figure 5A, the minimum number of moves for the trial is selected, and the latency (time to first move) measured. At that point, the program begins to count the time taken to solve the trial as the subject makes her/his moves on the second screen (Figure 5B). In the classic mode, the screen in Figure 5A is omitted.

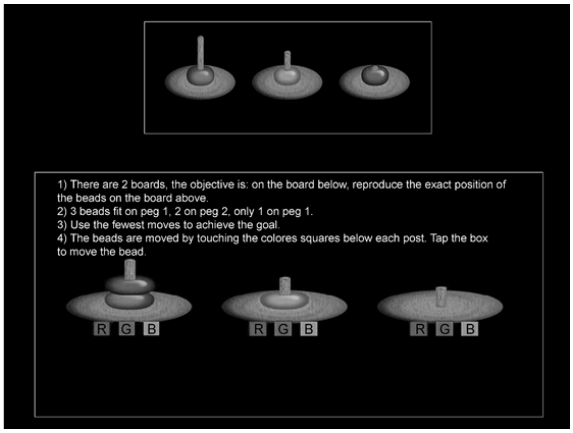

Figure 4. Instructions screen.

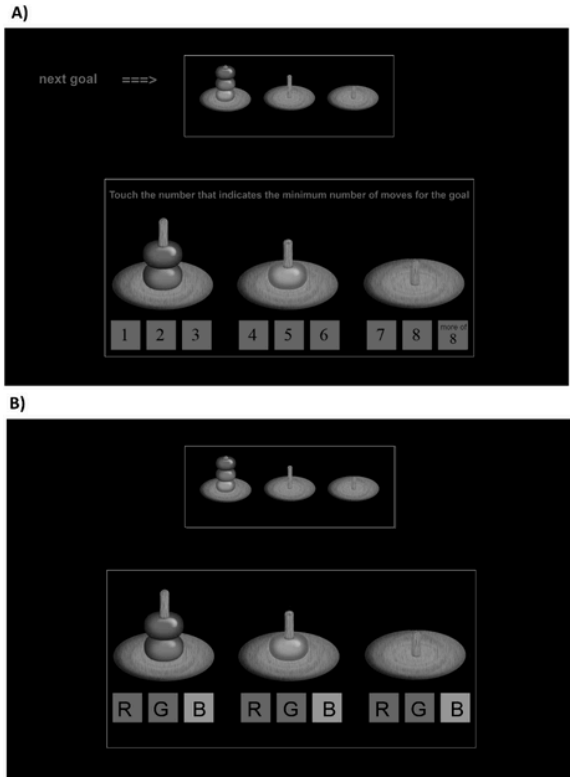

Figure 5. Example of a trial.
Note: A) Screen to select the minimum number of moves for the trial (planning-previous mode). B) Screen to execute the moves needed to reach the goal. The upper screen in both A and B shows the target, the lower screen the starting position. R: red, G: green, B: blue.

During the task, a voice and sign on the screen indicate when an illegal move has been attempted. Those moves are not made, so the current position is preserved.

The exercise ends when (i) the goal is reached; (ii) the time limit assigned runs out; or (iii) the maximum number of moves allowed is reached. London2PC permits a maximum of 20 moves. If the target is not reached before the time runs out or within 20 moves, the program passes automatically to the next trial by showing the "next goal" sign. At the end of the session, a message appears in red: "End of the program". The examiner can exit the program at any time by pressing the Q key (a partial results file will be saved).

London2PC has the capacity to evaluate a wide range of parameters that can be grouped as: 1) success or accuracy of solution; 2) efficiency of the solution; 3) speed of performance and planning during the solution; and 4) rule breaks during the solution. In light of Berg's [2] emphasis on using multiple performance measures to better evaluate various aspects of a single construct, London2PC was designed to provide a more complete perspective on subjects' skills or levels of planning.

London2PC, therefore, works with the classic parameters to facilitate evaluation but adds those introduced in the new modality (planning-previous mode). As mentioned above, to calculate the score for the number of moves, the minimum number required to reach the target is subtracted from the total moves made. This measure is inversely related to the task difficulty index (Cepeda *et al*., 2015), which is expressed between 0 and 1 and calculated by the formula:

$$p = A/N$$

where p = the difficulty index of the goal; A = the minimum number of moves required to reach the goal, and N = the total number of moves made. If the trial was executed with the minimum number of moves, the moves score will be 0, and the difficulty index 1. In contrast, the greater the number of moves per trial, the larger the move score above 0, but the number for the difficulty index will approach 0. All these measures can be used to evaluate individual trial execution by providing information on efficiency levels.

Additional quantitative variables that can be obtained are mentioned below.

Results File

London2PC saves the execution times for each goal in the results file (Figure 6). For each one, this file shows the sequential number of the goal followed by the number assigned by London2PC, as in Table 1, and, in parentheses, the minimum number of moves assigned. Four columns follow: the first is the number of the move attempted; the second is the position requested by the subject (according to Figure 2); the third indicates whether the requested move was correct (C) or incorrect (I); the fourth keeps track of the elapsed time, in seconds. The next line shows whether the goal was achieved (complete exercise) or not (incomplete). A summary of results indicates total moves, correct moves, incorrect moves, the moves' score (total moves *minus* minimum moves), latency to first move, execution time (total time of the exercise *minus* latency to first move), total execution time, and total accumulated time. Global results of the goals from the session are concentrated at the end of the file: number of goals achieved, goals achieved with the minimum number of moves, total moves' score (sum of the scores for moves on all goals), sum of latencies to first move, total execution time (the sum of the execution times of all goals), total test time, and the date on which the session was performed.

In the planning-previous mode, a row is added after the sequential number of the goal to show the number of proposed moves, followed by correct or incorrect moves, as appropriate, and latency times. At the end of the file, two additional rows appear: the total hits for the number of moves, and the average response time to the number of moves.

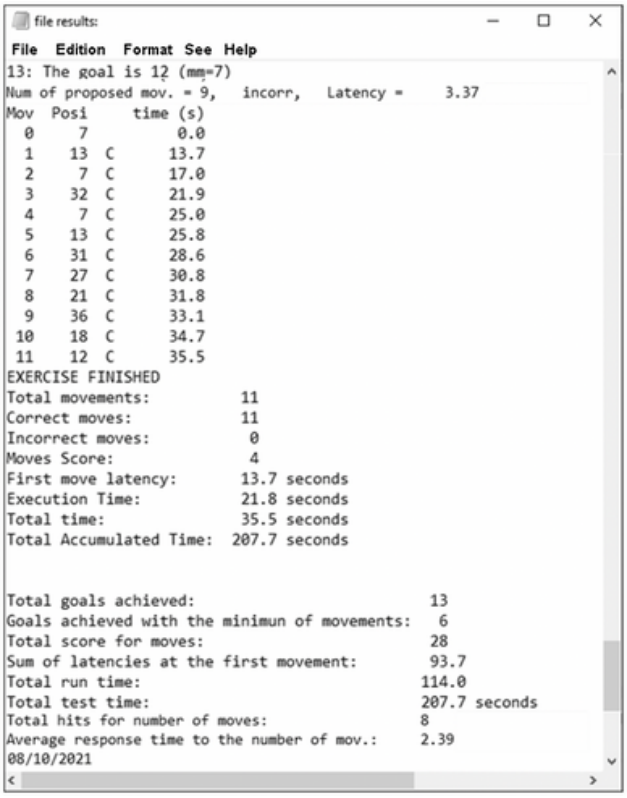

Figure 6. Example of a results file obtained after the execution of London2PC.

Software and Hardware Requirements

Program execution requires a PC-compatible computer with at least a Pentium processor and one megabyte of RAM.

The program works with any version of the Windows operating system. It was written in the Delphi programming language (v. 5). The executable program is London2PC.EXE. It does not require special installation, only copying, including the 36 images shown in Figure 2. The output file is in ASCII code and requires very little storage space.

Subjects can perform their moves to reach the target using either the keyboard (we recommend a mini numeric keyboard connected to the USB port), the mouse to point on the screen or, if a touch screen is available, by tapping directly on the screen. Nine keys of the numeric keyboard are used: 3 correspond to the red bead (7, 8, 9), 3 to the green bead (4, 5, 6), and 3 to the blue bead (1, 2, 3). These keys simulate the position of the beads on the 3 posts. Numbers 1, 4, and 7 correspond to the 3 beads at position 1; 2, 5, and 8 to the beads at position 2; and 3, 6, and 9 to the beads at position 3 (Figure 7). The screen also shows 3 colored squares under each post that perform the same function as the keys (they can be clicked on with the mouse or touched with the finger on a touch screen).

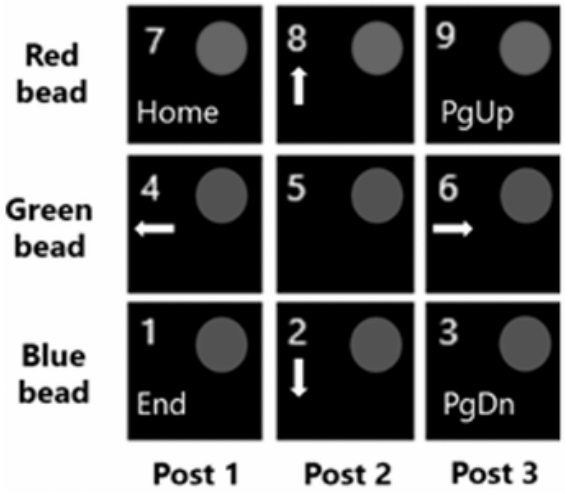

Figure 7. Numeric keyboard representation for executing London2PC.

Results

Application

To test the London2PC software in its new modality, 13 participants were evaluated (2 women). Subjects had an average age of 22.07 years (range 19-33), normal levels of attention and concentration evaluated by the Neuropsi battery (Ostrosky-Solís et al., 2013), and similar educational levels. Data were obtained following international ethical guidelines for studies involving human subjects (Helsinki Declaration, APA ethical standards).

Table 2 shows the cumulative data for all participants across the 10 trials. The first section shows the trial number and its minimum possible number of movements. The second displays the responses in the planning modality, while the third shows the responses on the classic modality of the Tower of London task.

Table 2. Cumulative data obtained from participants while performing the London2PC program.

Trials	Minimum amount of moves	Given proposal	Planning latency	Total movements	Move score	Latency to first move	Execution time	Total execution time	Time violation
1	3	3	10.73	3.31	0	2.65	5.86	8.52	0
2	3	3	13.33	3.31	0	3.98	4.93	8.94	0
3	3	3	10.15	3.15	0	3.94	3.33	7.28	0
4	4	4	12.89	4.08	0	4.38	5.19	9.58	0
5	5	5	40.58	9.85	0	4.72	56.22	50.21	0
6	6	6	43.56	8.77	1	9.12	26.09	35.22	0
7	6	6	37.73	7.38	0	8.52	20.14	28.66	0
8	7	6	35.57	8.31	0	12.42	26.15	38.57	0
9	7	8	21.74	7.92	0	3.21	16.80	20.02	0
10	7	7	36.89	8.77	0	4.66	26.36	31.03	0
Average			263.17	64.85		57.60	191.07	238.03	

Note: Given proposal, Move score and Time violation are in mode; the rest are mean.

Discussion

London2PC is a computerized task that allows researchers to evaluate the planning that is required to achieve goals. Due to the relation of this cognitive function to the functioning of the prefrontal cortex, this test can be used in both research and clinical evaluations. The program's precision in recording response times and performance –per exercise or per execution of the complete task–flexibility, and ease of handling the results represent significant advantages over earlier versions. In addition, this computerized version facilitates remote applications because it does not require installation. Subjects only need to follow a few simple steps to correctly execute the program. The requirements to run the program are minimal, but it only works on Windows operating systems. London2PC is available free of charge from the authors by formal request, but credit must be acknowledged for it use. It is important to note that the results presented correspond to a functionality test aimed. Accordingly, a formal validation study remains pending, given the small sample size used in this initial implementation.

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