How Do We Assess Executive Functions ? A Systematic Review of Tasks and Processes for Inhibition, Updating and Shifting

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Abstract

Executive functions are essential for adaptive behavior but there is great variability in the measure of these functions and the literature mostly focuses on tasks rather than the processes involved in those tasks. The adoption of a process-based rather than a task-based approach may improve the assessment of these functions. This study aimed to systematically review literature on how researchers measure inhibition, updating and shifting, for an integrative view of the tasks used and the processes involved in those tasks. The PsycInfo database was searched and we included studies measuring inhibition (n = 844), updating (n = 844) or shifting (n = 1048) among human participants and with performance-based measures, regardless of the population investigated or the type of tasks. We collected data regarding the tasks used, the participants' age and disorder. Then, we proposed a taxonomy of the processes involved in these tasks. Results show that researchers use many different tasks to measure the same concept but these tasks can engage very different processes. In addition, the participants' age or disorder has a significant effect on the assessment of these functions. The terms " inhibition ", " updating " and " shifting " may have different meanings depending on the population included. Our review underlines the importance of using multiple tasks to measure inhibition, updating or shifting, and reflecting on the processes involved in these tasks. More broadly, we suggest adopting a process-based rather than a task-based approach.

Keywords: Executive function ; Process-based approach ; Inhibition ; Shifting ; Updating

Introduction

Executive Functions

Executive functions are a multidimensional concept (Dias et al., 2023) covering a set of high-level (Collette et al., 2006 ; Jurado et al., 2007) and goal-directed (Dias et al., 2023) processes whose principal function is to facilitate adaptation to new or complex situations (Collette et al., 2006 ; Dias et al., 2023). Their structure is still subject to debate but the literature has been structured around the hypothesis that they show both unity and diversity (Miyake et al., 2000). The most studied executive functions are inhibition, updating and shifting. As such, they offer a common vocabulary to researchers.

Inhibition Inhibition is the capacity to " suppress " (in the meaning of " to prevent from starting or continuing "), such as suppressing previously prepared automatic responses (Hung et al., 2018 ; Idowu et al., 2023 ; Neubert et al. 2010) or prepotent but inappropriate responses (Blasi et al., 2006 ; Hung et al., 2018). Furthermore, many authors propose an additional subdivision with several components (e.g., Friedman & Miyake, 2004 ; Nigg, 2000), reflecting the actual difficulty to define this concept.

Updating Updating in working memory consists of actively modifying stored information in working memory by removal of outdated items, inclusion of new items and/or modification of stored information (Ecker et al., 2014b ; Rac-Lubashevsky et al., 2016). Ecker and colleagues (2010) break down updating in three independent subprocesses : retrieval, transformation and substitution. Substitution would be the only process unequivocally contributing to the unique variance of updating and it can be divided into two subcomponents : removal of outdated information and encoding of the updated information (Ecker et al., 2014a, 2014b). Removal would be the one specific to updating. Thus, a task that would not imply removal of outdated information should not be considered as an updating task.

Shifting The ability to switch between things (e.g., stimuli, responses, tasks) is termed " shifting ". Shifting can occur between many things, including stimuli, responses, cognitive sets, or even rules (Kim et al., 2011 ; Ravizza & Carter, 2008). We must distinguish local switch costs and global switch costs (Kiesel et al., 2010 ; Meiran et al., 2000 ; Rogers & Monsell, 1995). In the same vein, predictable switches from random switches involve different processes (Koch, 2005 ; Monsell, 2003 ; Shahar & Meiran, 2015).

Task-based vs. Process-based Approach

Executive functions are hard to measure. Since they are characterized by their regulation function on other cognitive functions (Dias et al., 2023), they can't be applied in isolation. Thus, it is difficult to isolate the specific variance attributable to executive functions. Furthermore, boundaries between executive functions are rather vague, such that one task can be said to involve all executive functions at the same time. We suggest that some of these difficulties might be resolved by adopting a process-based rather than a task-based approach.

The task-based approach implies to consider each task as involving mostly updating, inhibition or shifting. This approach is not always sufficient, for instance it cannot explain differences between an N-back task with rare match trials and an N-back task with frequent match trials. With a process-based approach, tasks would not be considered as

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“ updating ” or “ inhibition ” tasks but as tasks involving different subprocesses. The N-back task could be considered as a task requiring us to remember the last X stimuli of a continuous sequence with no transformation, and it may also involve other types of processes depending on the specific features of the tasks (e.g., if “ Match ” trials are rare).

Thus, the process-based approach provides a finer grain of analysis, allowing us to consider several executive functions and several sub-processes of each executive function involved in the same task. Similarly, the task-based approach is not sufficient to explain the low correlations observed in tasks measuring the same executive function (e.g., Miyake et al., 2000). By contrast, the process-based approach proposes that each task involves different sub-processes, thus explaining these low correlations. Thus, adopting a process-based approach would improve our understanding of inhibition, shifting and updating, and their assessment.

Previous reviews

Reviews investigating the measures used to evaluate executive functions highlight the lack of reliable and valid assessment tools (Berardi et al., 2021). In addition, the tools identified differ from one review to another, underlining the diversity of the measures used in the literature. However, these reviews were all interested in a specific population, such as adults with acquired brain injuries (Lebely et al., 2024 ; Mueller et al., 2021 ; Poncet et al., 2017). As such, they have helped to understand how we can measure executive functions in these populations but they did not provide a fine analysis of the processes involved in the measures used. An integrative view is needed to reflect on the different types of processes involved in executive functions’ tasks.

The present review

The aim of the present review is to provide a synthesis of the tasks used by researchers to measure inhibition, updating and shifting, and of the processes involved in these tasks. We suggest that some of the assessment difficulties might be resolved with a process-based rather than a task-based approach. Hence, a classification of the processes involved in executive functions’ tasks is needed. We aim to systematically review the tasks and types of executive processes assessed in the literature. The first main goal was thus to investigate the tasks used to measure inhibition, updating and shifting. The second main goal of this review was to investigate the specific processes involved in these tasks.

Method

We adhered to the PRISMA 2020 guidelines for systematic reviews. The search was performed on the PsycInfo database, with the EBSCO interface.

Studies were considered eligible for inclusion if they measure one of the three core executive functions (i.e., inhibition, updating and shifting) among human participants and with behavioral measures. Exclusion criteria were : (a) inappropriate type of publication (e.g., review, meta-analysis, opinion study, book chapter), (b) absence of human participants, (c) absence of behavioral measure to evaluate specifically the executive function investigated, or (d) publication in a different language than french or english.

For studies included for a thorough reading, we looked only at the “ Method ” section of these studies to identify the measure(s) used to evaluate the executive function we were interested in (i.e., inhibition, updating or shifting). The authors must describe explicitly the task as a task targeting that function.

After collecting the tasks used, we categorized them according to the processes supposedly necessary to perform them. Then, we proposed definitions of each category, from which we could systematically include the tasks identified in one of these categories. This allowed us to create pivot tables, by counting the number of unique references for each category of tasks.

The final table obtained, for each function, contained the following columns : reference, year of publication, task, age, disorder and reliability. The age categories were the following : babies ($X < 2$ years old), preschoolers ($2 \leq X < 4$ years old), children ($4 \leq X < 12$ years old), adolescents ($12 \leq X < 18$ years old), adults ($18 \leq X < 60$ years old) and older adults ($60 \leq X$ years old). The disorder categories were the following : no disorder, brain injuries (e.g., stroke, head trauma), pathological aging (e.g., Alzheimer, Parkinson), neurodevelopmental disorders (e.g., ADHD, dyslexia), psychopathological disorders (e.g., depression, bipolar disorder), and schizophrenia or related disorders.

For each of the three functions, a blind triple coding was realized on 10 selected studies and a blind double coding was realized on 100 other studies. As a whole, the inter-judge agreement was 91 % for updating (total agreement of 142 out of 156 tasks), 94 % for inhibition (total agreement of 156 out of 166 tasks), and 87.1 % for shifting (total agreement of 128 out of 147 processes).

Results

Inhibition

For inhibition, the search was made with the terms “ inhibition ” (AB) AND “ cognitive control or executive functions ” (AB) AND “ inhibition ” (KW). Launched on 03 November 2023, this search yielded 1061 results and 844 results were included for further analysis. We found 9 inhibition tasks that were present in at least 2.5 % of the studies, but most of the studies used GoNoGo (33.5 %), Stroop (27.5 %) or Stop Signal (23 %) tasks. Most studies do not provide reliability coefficients from their empirical data (93.6 %). Looking at the specific processes involved in these tasks, we proposed 12 inhibition processes and found that most of them are frequently investigated, but some

remain rare (e.g., Internal inhibition of mnesic traces, Self-control, Motivational inhibition). In addition, there was little diversity in the tasks used to measure specific inhibition processes, as they are each mostly investigated with a limited number of tasks and studies tend to use only one task, thus investigating only one specific inhibition process. Finally, researchers mainly investigated healthy adult participants and they tend to use different tasks depending on their participants' age or disorder. They also tend to investigate different inhibition processes depending on their participants' age.

Updating

For updating, the search was made on 11 October 2023 with the terms " updating " (AB) AND " working memory or cognitive control or executive functions " (AB). 1271 results were obtained and 844 were included for further analysis. We found 6 updating tasks present in at least 2.5 % of the studies, but the frequency of N-back tasks (42.2 %) is much greater than the others. Most studies do not provide reliability coefficients from their empirical data (88.4 %). Looking at the specific processes involved in these tasks, we proposed 10 updating processes and observed that only a handful of these processes are frequently investigated. In addition, there was little diversity in the tasks used to measure specific updating processes, as they are each mostly investigated with a limited number of tasks and studies tend to use only one task, thus investigating only one specific updating process. Furthermore, a great number of studies measured updating with tasks that don't involve substitution and thus don't fulfill our criteria to be considered as updating tasks (e.g., Span tasks). Regarding the participants included in these studies, researchers mainly investigated healthy adult participants and they tend to use different tasks and investigate different updating processes depending on their participants' age, but not depending on their participants' disorder.

Shifting

For shifting, the search was made with the terms " shifting " (AB) AND " cognitive control or executive functions " (AB). On 8 January 2024, the search yielded 1430 results and 1048 were included for further analysis. We found 13 shifting tasks present in at least 2.5 % of the studies, but TMT (24.7 %) and Card sorting (21.4 %) tasks showed the greatest proportion of publications. Most studies do not provide reliability coefficients from their empirical data (91.7 %). Looking at the specific processes involved in these tasks, we proposed 6 shifting processes and found that most of them are frequently investigated, but some remain rare (e.g., Perceptive shifting, Strategy shifting, Shifting between self-generated rules). In addition, we saw a great number of different tasks used to investigate each shifting process, but most of them are not used frequently, such that each shifting process is mainly investigated with the most frequently used shifting tasks and studies tend to use only one task, thus investigating only one specific shifting process. Finally, researchers mainly investigated healthy adult participants and they tend to use different tasks and investigate different shifting processes depending on their participants' age or disorder.

Discussion

We found a great heterogeneity of the tasks used to measure a common function. Hence, tasks are used in an interchangeable way that is not compatible with the complexity of executive functions. In addition, most studies used only one task, which does not allow the study of a function in its globality. Furthermore, we found a great heterogeneity of the processes involved in those tasks. Also, participants' age and disorder has a significant effect on the tasks used and the processes investigated. Hence, the terms " inhibition ", " updating " and " shifting " may not have the same significance depending on the population studied. Finally, we noted some confusions that could be attributed to the prevalence of the task-based approach. For instance, we observed some confusion in the understanding of the updating process, reflected in the massive use of Span tasks. Span tasks typically don't require any removal of information, they rather imply the encoding of more and more stimuli. Hence, a significant part of studies measuring updating use tasks that we do not consider as updating tasks because they don't involve substitution of information in working memory.

This demonstrates the adoption of a task-based approach in the literature : researchers mainly focus on the tasks rather than on the processes involved in these tasks. To alleviate the operational difficulties of executive functions, we first need a common framework to define and to assess these functions. This may be possible with a process-based rather than a task-based approach. We suggest that adopting a process-based approach could improve the assessment and the study of executive functions. The task-based approach consists of viewing executive functions only under the prism of a particular task.

By contrast, the process-based approach implies to reflect on the specific processes involved in the tasks used. This approach could improve the estimation of an individual's score on executive tasks. For instance, in developmental psychology, assessing a specific cognitive function implies assessing each aspect of this function. This also applies in a clinical setting : improving the assessment of executive functions can help the clinician identify more precisely the patient's difficulties. In addition, this approach can help in the study of executive functions' structure. Factorial analyses of executive functions often demonstrate both diversity and unity of executive function, but with rather low correlations (e.g., Miyake et al., 2000). These low correlations can not be explained by a task-based approach. Using a process-based approach, we see how different tasks can involve different processes, thus explaining low correlations.

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