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Citation for published version

Wallace, Gregory L. and Peng, Cynthia and Williams, David M. (2017) Interfering with Inner Speech Selectively Disrupts Problem-Solving and is Linked with Real-World Executive Functioning. Journal of Speech, Language, and Hearing Research, 60 (12). pp. 3456-3460. ISSN 1092-4388.

DOI

https://doi.org/10.1044/2017_JSLHR-S-16-0376

Link to record in KAR

http://kar.kent.ac.uk/64515/

Document Version

Author's Accepted Manuscript

Interfering with Inner Speech Selectively Disrupts Problem-Solving and is Linked with Real-World

Executive Functioning

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Abstract

Purpose: According to Vygotskian theory, verbal thinking serves to guide our behavior and underpins critical self-regulatory functions. Indeed, numerous studies now link inner speech usage with performance on tests of executive function. However, the selectivity of inner speech contributions to multi-factorial executive planning performance and links with real-world functioning are limited. Therefore, the present study seeks to fill this gap in our knowledge. **Method:** Fifty-one adults completed the Tower of London under two conditions: (1) articulatory suppression and (2) foot tapping as well as self-ratings of real-world executive functioning (utilizing the Behavior Rating Inventory of Executive Function-Adult version). **Results:** Interfering with inner speech selectively disrupted Tower of London performance over and above a simultaneous motor task (i.e., foot tapping). Furthermore, this selectivity in performance was linked with real-world self-monitoring. **Conclusion:** These results provide further evidence for specific links between verbal thinking and executive function (particularly using multifactorial tasks of planning) and suggest that inner speech might serve as a key intervention target in clinical disorders where executive function deficits are prominent.

Keywords: inner speech; executive function; planning; articulatory suppression; problem-solving

Introduction

In one of the most influential theories of language development, Vygotsky (1962) contends that verbal thinking or "thinking in speech" serves to guide our behavior and underpins crucial self-regulatory functions. According to Vygotskian theory as early language comes online, overt self-talk (i.e., private speech) emerges and becomes progressively more covert during the later preschool years until it is completely internalized (i.e., becomes inner speech) sometime in the early primary school years. This parallel development and interplay between language development and self-regulation has led to postulations of how inner speech and its disruption affects executive function (EF) in particular. EF is an omnibus grouping of various goal-directed and self-regulatory cognitive skills, including inhibitory control, working memory, flexibility, and planning (e.g., Miyake et al., 2000; Pennington & Ozonoff, 1996). There is an existing literature demonstrating a specific link between inner speech use and performance on EF tasks (for review, see Alderson-Day & Fernyhough, 2015; Winsler, Fernyhough, & Montero, 2009). For example, articulatory suppression (i.e., repeating words aloud, which prevents inner speech) disrupts working memory, set-shifting, and task-switching performance significantly more than structurally similar dual task conditions that do not interfere with inner speech (e.g., foot-tapping; Baddeley et al., 2001; Baldo et al., 2005; Emerson & Miyake, 2003). However, there is a debate about whether inner speech specifically supports higher-order and multifactorial tasks of planning. The ability to plan ahead is critical for efficient and successful navigation of one's daily life and this planning ability is conceptualized as a crucial component of EF (e.g., Pennington & Ozonoff, 1996). Prototypically, planning is measured in the laboratory using classic tower tasks, such as the Tower of London. In this and similar tower tasks (e.g., Tower of Hanoi or Tower or Toronto), participants are asked to move colored disks or beads, one at a time, across three pegs. In tower tasks participants are asked to utilize as few moves as possible to go from a starting configuration of disks/beads (used consistently across trials) to a new goal state for each problem. Planning ability is measured by the number of moves it takes to achieve the goal state; fewer moves are equated with better planning. However, tower tasks are not purely

measures of planning ability. They are in fact multifactorial in terms of cognitive demands, also relying on working memory, inhibitory control, and sustained attention, among other cognitive functions. Moreover, tower tasks are particularly reliant on inner speech utilization for success. According to Russell et al. (1999), tower tasks require holding in mind and applying 'arbitrary rules' throughout their execution, which suggests their requiring verbal mediation. Therefore, tower tasks, like many EF and problem solving tasks, call upon inner speech. Nevertheless, two dual-task studies (Phillips, Wynn, Gilhooly, Della Sala, & Logie, 1999; Holland & Low, 2010) have found that interfering with inner speech (e.g., via articulatory suppression) diminishes planning performance no more than interfering with non-verbal processing (e.g., via foot-tapping). However, given concerns about the validity of one of these studies (see Williams, Peng, & Wallace, 2016) and the strong theoretical reasons to believe that inner speech has a specific role in multifactorial tasks of planning, a more thorough examination of this issue is warranted.

Furthermore, prior investigations have largely failed to investigate associations between inner speech usage and real-world EF. There is a classic trade-off between ecologically valid assessment approaches that strive to be more representative of real-world functioning but lack the experimental control characteristic of laboratory-based assessments (Chaytor & Schmitter-Edgecombe, 2003). Inner speech has been linked with performance on laboratory-based EF tasks; however, extending this association with EF beyond the laboratory and into everyday settings would provide external validity for the role of inner speech in EF. This is important as it provides ecological validity to these lab-based inner speech findings and might serve to guide interventions that could facilitate self-talk in clinical disorders exhibiting both inner speech atypicalities (e.g., autism spectrum disorder [ASD]: Wallace et al., 2009; Whitehouse, Maybery, & Durkin, 2006; Williams, Bowler, & Jarrold, 2012; for review, see Williams et al., 2016) and real-world EF difficulties (e.g., Granader et al., 2014; Wallace et al., 2016).

Therefore, in the current study we hypothesize that interfering with inner speech usage via articulatory suppression impedes performance on a multifactorial task of planning, the Tower of London,

above and beyond a comparable interference task, foot tapping. Furthermore, we take an individual differences approach in the present study and predict that the impact of this interference on inner speech usage in the context of a well-controlled task will be associated with variance in self-rated real-world EF particularly the more socially focused components of EF, such as self-monitoring, consistent with Vygotsky's (1962) original postulations.

Methods

Participants

Fifty-one young adults (15 males, 36 females) with a mean age of 20.29 years (range: 18-37, SD = 3.53) were recruited for the study. Participants were recruited from a university campus and the surrounding community and were paid for their time. This study was approved by a university-affiliated institutional review board and informed consent was obtained from all participants.

Procedure

A computerized version of the classic Tower of London task (Shallice, 1982; for review, see Phillips, Wynn, McPherson, & Gilhooly, 2001) was administered to all participants. A "goal" panel of five different colored disks (each a different size) on three pegs was shown at all times on the top half of the computer screen, while the "manipulable" panel was directly below on the bottom half of the screen. Participants were asked to move the disks in the manipulable panel from its initial state to the goal state in as few moves as possible with no time limit on each trial and no instructions to "pre-plan."

All participants completed 24 trials: 12 trials under each of two conditions (with no time limit per trial). The Articulatory Suppression (AS) condition required participants to say one word ("Monday")

aloud to the beat of the metronome, set at one beat per second. The Foot Tapping (FT) condition required

participants to tap one foot to the beat of the metronome, also at one beat per second. FT is widely used

as a "control" task in dual-task studies of inner speech use, because it is structurally equivalent to

articulatory suppression, but does not interfere with verbal processing (see Emerson & Miyake, 2003,

appendix A). To familiarize participants with these novel procedures, three practice trials preceded each

experimental block of 12 trials.

Six Tower of London difficulty levels were sequentially presented for each condition (two trials

at each level): 2-move, 3-move, 4-move, 5-move, 7-move, and 9-move trials. The order in which AS and

FT conditions were completed was counterbalanced across participants. Following standard procedures,

the minimum number of moves required for each trial was subtracted from the actual number of moves

taken to complete the trial, generating a value that, when summed, comprises the number of extraneous

moves for each condition. The fewer extraneous moves taken to complete the problems, the better a

participant's planning ability. Finally, an index of the degree to which AS affected Tower of London

performance more than FT was calculated. A difference score was derived by subtracting the number of

extraneous moves in the FT condition from the number of extraneous moves in the AS condition.

However, because of significant skewness in these scores (and following Williams et al., 2012),

participants were split into two groups: a) those whose Tower performance was more negatively affected

by AS than by FT (n=32) and b) those whose Tower performance was either equally affected (n=3) or

more negatively affected by FT than by AS (n=16; total n=19). These groups were then compared on

their self-ratings of real-world EF (see below). See Table 1 for overall Tower of London performance

(collapsing across conditions).

Participants also completed the Behavior Rating Inventory of Executive Function-Adult self-

report version (BRIEF-A; Roth, Isquith, & Gioia, 2006). The BRIEF-A is a psychometrically sound and

age-normed questionnaire composed of 75 items rated by participants on the frequency in which an

activity presented a problem within the past month ("never," "sometimes," "often"). The items are

grouped into nine theoretically and empirically derived scales: Inhibit, Shift, Emotional Control, Self-Monitor (all four of which compose the Behavioral Regulation Index), Initiate, Working Memory, Plan/Organize, Task Monitor, and Organization of Materials (all five of which compose the Metacognition Index). These nine scales can be combined to form the Global Executive Composite. See Table 1 for BRIEF-A index and composite scores.

Data Analysis

A paired-samples t-test was used to assess whether participants differed in the number of extra moves needed to complete Tower of London items across the AS and FT conditions. An independent samples t-test was utilized to examine whether differences in real-world executive functioning (using the BRIEF-A) were observed in those who experienced greater interference from AS than FT compared those who did not.

Results

Participants made significantly more extraneous moves in the AS condition (M=4.67, SD=3.02) than the FT condition (M=3.20, SD=3.32), t=2.29, p=.03, d=0.46.

Treating the FT condition as baseline Tower of London performance, participants who experienced greater interference from AS than FT took significantly fewer extraneous moves to solve the problems on average (M=1.47, SD=1.80) than did those who experienced equivalent or less interference from AS than FT (M=6.11, SD=3.28; t=6.54, p<.001, d=1.75). Participants whose Tower of London performance was more negatively affected by AS than by FT (see Figure 1 for contrast in Tower London performance by group) also rated themselves as exhibiting significantly better (t=2.74, p=.01, d=0.76) self-monitoring scores on the BRIEF-A (M=45.97, SD=8.06) compared to participants whose Tower of

London performance was either equally affected or more negatively affected by FT than by AS (M=51.21, SD=5.57). No significant group differences were noted for the other scales of the BRIEF-A (all ps>.58, all ds<0.16).

Discussion

Several studies of adults have shown that articulatory suppression interferes significantly more with various aspects of EF (e.g., working memory, cognitive flexibility) than does foot tapping (or an equivalent non-verbal secondary task; e.g., Baddeley et al., 2001; Baldo et al., 2005; Emerson & Miyake, 2003). However, to our knowledge the present study is the first to establish that articulatory suppression has this selective effect on a multifactorial task of planning, which supports Russell et al.'s (1999) contention that tower tasks, with their reliance on keeping in mind and applying various rules, require verbal mediation and therefore tax inner speech. This represents an important finding because it supports the notion that efficient planning relies on inner speech use as found with other components of EF, such as working memory (e.g., Baddeley et al., 2001) and cognitive flexibility (e.g., Baldo et al., 2005; Emerson & Miyake, 2003).

Although on the group level AS interfered more with Tower of London performance than did FT, considerable individual differences also were observed. Capitalizing upon this variability in performance, comparisons were made between those who experienced greater interference from AS than FT (i.e., those more likely to use inner speech in the service of problem solving) versus those who did not. As predicted, adults who demonstrated more interference from AS than FT exhibited better self-monitoring, one aspect of real-world EF assessed by the BRIEF-A. This finding links inner speech usage with everyday self-regulatory skills, as would be predicted if taking a Vygotskian view. In the same vein, it is important to note that the Self-Monitoring scale from the BRIEF-A measures an individual's awareness of the impact of his/her behavior on others. In other words, there is a strongly social component to this aspect of

everyday EF, which might explain its unique association with inner speech interference effects. Nevertheless, it is also important to note that many aspects of everyday EF were not associated with inner speech utilization in the context of the Tower of London task. How these skills then translate to everyday EF demands remains an open question that future research should strive to answer.

It is important to consider the fact that AS was not universally more interfering than FT. Why this might be is unclear from the current study and could represent true individual differences in cross-modal dual-task interference effects. In other words, for some individuals near-simultaneous motor demands are as detrimental, or nearly as detrimental, to problem solving performance as suppressing inner speech via articulatory suppression. More work is needed to take an individual differences perspective to better understand why for some individuals dual-task interference effects vary by modality of the interfering task. Of course, methodological issues could also contribute to these findings. For example, it is challenging to truly equate verbal and motor interference effects (e.g., it is conceivable that inequity of interference occurred in the current study via a single motor action vs. speaking a two-syllable word aloud).

Although the current study was conducted with neurotypical young adults, it is important to consider the potential implications of this research, albeit somewhat speculative. For example, ASD is characterized by core impairments in (particularly early developing) social communication as well as restricted and repetitive behaviors. Therefore, a growing line of research has sought to examine inner speech usage in ASD as a potential cognitive mechanism driving EF impairments, including planning difficulties, which are commonly found in ASD (see Kenworthy et al., 2008; Wallace et al., 2016; Williams & Jarrold, 2013). Indeed, numerous studies now suggest that people with ASD under-utilize inner speech during EF, particularly multifactorial planning tasks (e.g., Holland & Low, 2010; Wallace et al., 2009; Williams et al., 2012; though see Williams et al., 2016). The clinical and real-world impacts of the underutilization of inner speech in ASD needs to be investigated further, given the potential for novel intervention approaches that could be implemented in classrooms and other everyday contexts. For

example, it is unclear whether inner speech use could be encouraged directly among people with ASD with a view to remediating self-regulation difficulties, or whether it would be more profitable to take a developmental perspective and focus on improving early social-communication skills. Perhaps only if individuals with ASD experience the typical course of inner speech development (i.e., via the internalization of communicative exchanges with others) will inner speech use be used in a truly purposeful way as a means of mediating cognition and behavior (see Diaz & Berk, 1995).

In summary, the present study provides additional evidence that verbal thinking and executive function, particularly when completing multifactorial tasks of planning, are intricately linked. Consequently, utilizing inner speech as an intervention target in clinical disorders where executive function deficits are prominent might prove fruitful in future investigations.

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Table 1. Overall Tower of London performance and Behavior Rating Inventory of Executive Function-Adult version (BRIEF-A) self-ratings for the full sample, the group showing greater interference from articulatory suppression (AS), and the group showing greater interference from foot tapping (FT).

	Full Sample (n=51)	>AS Interference (n=32)	>FT Interference (n=19)
Overall Tower of London Number of Extra Moves	7.86 ± 4.40	7.22 ± 3.67	8.95 ± 5.34
BRIEF-A Global Executive Composite	53.75 ± 9.81	53.81 ± 9.68	53.63 ± 10.30
BRIEF-A Behavioral Regulation Index	51.33 ± 8.86	50.75 ± 9.13	52.32 ± 8.53
BRIEF-A Metacognition Index	55.08 ± 10.74	55.63 ± 10.26	54.16 ± 11.73

Figure 1. Mean number of extra moves (±SEM) needed to complete the Tower of London problems under conditions of articulatory suppression (AS) versus foot tapping (FT) for the group showing greater interference from AS compared to the group showing greater interference from FT.