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The phenomenological influence of inner speech on executive functions

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Abstract

Inner speech is an internal verbalisation that can contribute to solving complex tasks. Variations of Inner speech and its influence on specific executive functions in typically developing adults is an area of research that is underdeveloped. This study used the Varieties of Inner Speech Questionnaire (VISQ) and split participants into high and low inner speech quality levels. Each participant completed three conditions; standard (no instruction to use or inhibit self-talk), articulatory suppression (which aims to block a person's inner and private speech by omitting its usage) and overtly verbalising (talking out loud), to investigate the qualitative influence of inner speech on two measures of executive function. Experiment 1 (The Tower of London) showed no effect of inner speech quality levels on any of the three conditions; findings suggest that planning is not dependent upon inner speech. Experiment 2 (Card Sorting Task) indicated that lower quality levels of inner speech significantly benefited task performance; findings suggest that higher quality levels of inner speech are significantly detrimental to cognitive flexibility. These results are essential for understanding the inter-individual role of inner speech quality in supporting complex executive functions. Additionally, the findings advocate that inner speech has separable trajectories for specific executive functions. Understanding the possible interactions between inner speech quality and specific executive functions could assist in maximising performance and interventions for typical and atypical populations.

Keywords: Inner speech; Executive functions; Tower of London; Card Sorting Task

1. **Introduction**

Individuals regularly report an inner voice (Morin, Uttl, & Hamper, 2011; Baars, 2003; Carruthers, 2002), a voice that is produced in the mind - nobody can hear it; it is private to one's self. The inner voice is also known as verbal thought, covert self-talk or inner speech and has a vital role in everyday tasks, including complex tasks, such as reading (Alexander & Nygaard, 2008; Kurby, Magliano & Rapp, 2009) and writing (Puranik & Lonigan, 2012). However, the influence of inner speech on executive functioning is a much debated topic (for a review see, Alderson-Day & Fernyhough, 2015). Executive functions are vital for goal-directed behaviour (Best & Miller, 2010; Barkley, 2012), and encompass a wide range of cognitive functions, such as planning, cognitive flexibility, problem-solving, decision making, self-control and inhibition (for a review see, Alvarez & Emory, 2006). There are a range of theoretical perspectives on inner speech, one perspective states that inner speech is a subcomponent of working memory that aids with rehearsal and storage of verbal information and is regarded as having only a representational role in executive functioning (Baddeley & Hitch, 1974; Baddeley, 2001). More recently, researchers have established the *embodied situational hypothesis* that characterises inner speech as having similar structural factors as overt speech (Bergen, 2012). However, Lev Vygotsky's (1987) *cognitive development model* has been the most influential and coherent in attempting to explain this phenomena (Alderson-Day & Fernyhough, 2015; Morin & Uttl, 2012).

Vygotsky's (1987) cognitive development model proposes that inner speech is a developmental process, originating from external speech. Through social exchanges, children begin overtly talking to one's self to complete cognitive tasks; as such speech becomes internalised, inner speech is produced (Vygotsky, 1987). According to the cognitive development model the usage of verbal strategies for planning and cognitive flexibility are viewed as a domain-general shift in early childhood and is verbally mediated from the age of seven (Al-Namlah, 2006). However, private speech mutterings still occur in adolescence and adulthood when completing cognitively demanding tasks (Duncan & Cheyne, 2002; Duncan & Tarulli, 2009). Though this theory is readily critiqued, it is suggestive of the role of inner speech on regulating higher cognitive functions. (Vygotsky, 1987; McCarthy-Jones & Fernyhough, 2011; Fernyhough, 2008). However, there is a lack of research that investigates inner speech across a range of cognitive domains (Alderson-Day & Fernyhough, 2015). An exception to this is a study by Fatzer and Roebers (2012) who found that articulatory suppression negatively influenced performance in three types of executive functioning tasks. Articulatory suppression can take the form of reciting the days of the week or repeating a word out-loud whilst completing the primary task. It aims to block a person's inner and private speech by omitting its usage in the working memory process. If a task relies on inner speech for successful completion then applying articulatory suppression to the primary task should significantly impair performance (Murray, 1967). The researchers found that articulatory suppression had impacted upon each of the experiments and concluded that inner speech is a domain general tool that mediates specific parts of each task.

Expanding upon Vygotsky's cognitive development model, Fernyhough (2005, 2008) proposed the dialogic thinking framework which has four levels. According to Fernyhough, dialogic inner speech consists of two internal levels; expanded (thinking in full sentences) and condescend (thinking in pure meanings or single words) inner speech (Fernyhough, 2008). Combined, these levels can lead to the creation of an inner dialog which can hold multiple perspectives simultaneously (Fernyhough, 1996, 2008). The final two levels are external; private speech and external dialog. Private speech consists of external mutterings and external dialog has a give-and-take structure that is conversational. In a similar nature to the cognitive development model, it is suggested that a developmental trajectory enables speech to become internalised to become inner speech. According to Fernyhough (2008, 1996) the inner speech dialog is able to mediate higher mental functions because it can hold multiple perspectives at one time which can help facilitate problem solving (Williams, Bowler and Jarrold, 2012). In addition, Fernyhough proposes that when children and adults are presented with a cognitively demanding task they are able to transition between these different levels in order to successfully complete a task (Fernyhough, 2005, 2008).

In an attempt to quantify expanded/condensed inner dialogue McCarthy-Jones and Fernyhough (2011) developed the Varieties of Inner Speech Questionnaire (VISQ). This questionnaire explores the quality of an individual's inner speech and includes subscales dialogic, condensed/expanded, self-evaluative and other people in inner speech. However, its usage has mostly been attributed to investigating verbal hallucinations (Moseley, Smailes, Ellison & Fernyhough, 2016; De-Sousa, Sellwood, Spray, Fernyhough, & Bentall, 2016). Therefore, this relationship between inner speech and executive functions should be investigated further with typically developing adults. Research has failed to integrate the VISQ with executive functions utilising an experimental design and using a sample of typically developing adults and account for potential variation in the quality of inner speech and its influence on executive functions. Research has focused upon populations with atypical development, particularly where deficits or dysfunctions of inner speech are apparent, such as autism and schizophrenia (Hill, 2004; Allen et al., 2007) and these atypical populations are associated with having impaired executive functions (Pennington & Ozonoff, 1996; Ozonoff & Jensen, 1999). In an attempt to explore the quality of inner speech (high or low) in typically developing adults, and the possible mediating effects this has on executive functions, the current study used two gold standard experimental assessments: the Tower of London and the Card Sorting Task.

1.1 The Tower of London

The original Tower of London (TOL) task was developed by Shallice (1982) to test frontal lobe lesion patients, but it is now widely used in clinical settings (Andrews, Halford, Chappell, Maujean & Shum, 2014; McKinley et al, 2008; Berg and Byrd, 2002) and non-clinical populations (Kaller, Rahm, Spreer, Mader & Unterrainer, 2008; Ouellet, Baeuchamp, Owen & Doyon, 2004) to assess executive functions, such as planning, problem-solving, decision making, cognitive flexibility and working memory. The task requires participants to move balls onto varying sized pegs using the least amount of moves possible. The current study aimed to increase planning and therefore working memory, thus it utilises adapted TOL methodology as proposed by Lidson et al., (2010).

There is contrasting evidence as for the extent to which inner speech has a central role in successful task performance in TOL. Wallace, Silvers, Martin and Kenworthy (2009) compared autistic adolescences and typically developing adolescences. Each adolescence group completed the task in a standard and articulatory suppression condition and attempted to complete the task in the least amount of moves. The results showed that typically developing adolescences produced less moves in the standard conditions compared to adolescences with autism. This result is in accordance with Fernyhough's (2005, 2008) dialogic thinking framework with typically developing adolescences with high inner speech quality being able to utilise their inner speech and private speech to benefit the cognitively demanding task. Conversely, social interactional difficulties faced by adolescents with autism could affect the construction of the developmental trajectory and therefore the quality of inner speech (Vygotsky, 1987; Fernyhough, 2005, 2008) thus negatively impacting task performance. As typically developing adolescents produced significantly more moves than those with autism in the articulatory suppression condition, it is suggested that planning is mediated by inner speech only when speech deficits are not present (Hill, 2004). However, the experiment failed to detail the meaning of *standard* condition, which could enable typically developing adolescences to enhance their performance in comparison to autistic adolescences by utilising private speech (Fernyhough & Fradley, 2005; Fernyhough 2005, 2008; Vygotsky, 1987).

Williams et al (2012) investigated inner speech utilising an adult population and included a 'silent' condition. The results indicated no effect between the two sets of participants for the silent condition, suggesting that typically developing adults did not gain an advantage from their spontaneous use of inner speech and were also not able to incorporate private speech into their strategy, which could increase their performance (Fernyhough & Fradley, 2005; Fernyhough, 2005, 2008; Vygotsky, 1987). The results for the articulatory suppression mirrored the results of those of Wallace et al (2009), supporting the concept that articulatory suppression interfered with the inner speech dialog as typically developing individuals were not able to hold multiple perspectives at one time that affected problem-solving ability (Fernyhough, 2008, 1996). In conclusion, Williams et al. (2012) stated that typically developing adults employed inner speech for effective planning more than those with autism, but those with autism were able to utilise 'visual thinking' in order to perform similarly to the typically developing adults in the silent condition, which is plausible given the autistic framework developed by Kunda and Goel (2010).

To exploit the concept of external dialog and to investigate its role in relation to inner speech a planning study by Harvey, Galletly, Field and Proeve (2009) tested those with schizophrenia in a standard and overtly verbalise condition in a tower task. They hypothesised that those with schizophrenia should benefit from verbalising their strategy in comparison to the standard condition as verbalisation should guide decision-making and help them develop a top-down cognitive strategy to improve performance (Harvey et al., 2009; Stratta et al., 1996). The results showed that participants did not gain any benefits nor adverse effects in comparison to the standard condition. Conversely, the researchers found an effect on a number letter switching task that incorporates cognitive flexibility and working memory, which are described as higher order executive functions (Harvey et al., 2009). Although the executive functions incorporated in the tower task also incorporates higher order executive functions (Welsh, Revilla, Strongin, & Kepler, 2000). To increase this, the current study places a larger emphasis on planning and therefore working memory by forcing participants to plan ahead in the Tower of London task (Lidstone et al., 2010; Cohen, 1996). This adaption should classify the current study as equal in task difficulty to card sorting and switching tasks which could provide an advantage for those with a low quality of inner speech because it will help them guide their behaviour (Stratta et al, 1996), but the alteration might still have no effect on these individuals as the executive function the tower task targets is primarily planning rather than sorting and switching. In contrast, Fernyhough's (2005, 2008) dialogic thinking framework allows individuals to shift through internal and external levels in order to successfully complete a cognitive task. Therefore, it could be said that participants with high inner speech quality would perform better on the task because they have developed a stronger dialogic thinking framework than participants with low inner speech quality.

1.2 The Card Sorting Task

The Card Sorting Task (CST) is a neurological assessment task that aims to measure executive functioning, namely cognitive flexibility, problem solving, decision making, working memory and self-control (for review see Alvarez & Emory, 2006). It is the most widely used measure of executive functioning (Baddeley, 1996; Barceló & Knight, 2002; Stuss & Levine, 2002). The task requires participants to match 48 cards to 4 stimuli cards according to the experimenter's rule. Their aim is to get as many 'correct' answers as possible and avoid making perseverative errors. Perseverative errors are defined as the continued sorting of a category that would have been correct for the previous category and is the main dependent variable in measuring cognitive flexibility (Heaton, 1993, 1981).

Empirical evidence for the CST supports the findings that are found in the silent, articulatory suppression and verbalise conditions to that in the Tower of London task, although focused empirical evidence is limited in this domain. Russell-Smith, Comerford, Maybery and Whitehouse (2013) compared typically developing children and children with autism among four conditions; silent, articulatory suppression, overtly verbalising and concurrent mouthing. The results showed that there was no effect in the silent condition between typically developing children and children with autism; therefore refuting the concept that inner speech dialog is able to mediate higher mental functions (Fernyhough, 2008, 1996). However, a significant effect was produced in the articulatory suppression condition, showing that typically developing children produced more perseverative errors than autistic children – significant effects were also found in a study on adults (Baldo et al., 2005). These results suggest that typically developing individuals utilise inner speech in their processing of the task and supports the concept that the internal dialog is able to mediate higher mental functions (Fernyhough, 2008, 1996) but inner speech is not mediated in individuals with autism (low levels of inner speech quality). Surprisingly typically developing children slightly benefited from overly verbalising their strategy in comparison to those with autism. However, further inspection indicates that these children were in their middle elementary years and were not quite at an age whereby inner speech is fully developed (Winsler & Naglieri, 2003), suggesting equally low inner speech quality. None-the-less this research indicates that typically developing children can also benefit from overtly verbalising. Perry (2001) reported that those with schizophrenia benefited from overly verbalising strategies in the Wisconsin card sorting task, supporting the notion that individuals with a low inner speech quality will benefit from overtly verbalising and echoing the findings of others on another type of cognitive flexibility task (Harvey et al., (2009). In contrast, Fernyhough's (2005, 2008) dialogic thinking framework allows individuals to shift through internal and external levels in order to successfully complete a cognitive task. Therefore, it could be argued that participants with high inner speech quality would perform better on the task because they have developed a stronger dialogic thinking framework than participants with low inner speech quality.

Therefore, the present study aims to investigate inner speech quality through the administration of the VISQ and apply this to assess participants executive functioning on the TOL and CST task. Each experimental method will consist of three conditions; standard, articulatory suppression and overtly verbalise which will assess the possible interactions between inner speech quality and executive functions. Current evidence is uncertain as to whether participants with a high or low inner speech quality will produce similar scores in both experiments during the standard condition. In contrast, Fernyhough's (2005, 2008) theory would argue that participants with a high inner speech quality will produce less errors in both cognitive tasks than participants with low inner speech quality because inner speech dialog is able to mediate higher mental functions. Participants who are classified as having high inner speech quality will perform significantly worse under articulatory suppression in both experiments than participants with low inner speech quality because articulatory suppression will interfere with the participants' ability to hold multiple perspectives in the mind at once (Fernyhough, 2005, 2008). Finally, current evidence for both experiments is uncertain as to whether participants with high or low inner speech quality will produce fewer errors on the overtly verbalising condition.

2 Method

2.1 Design Overview

Inner speech quality was a between subjects measure (high and low). Each of the two measures of executive functions (Tower of London and Card Sorting Task) were repeated measures that consisted of 3 conditions (standard, articulatory suppression and verbalise strategy).

2.1.1 Participants

33 participants (Male 16; Female 17) were recruited through Nottingham Trent University's Research Credit Scheme (SONA) and the university's participant recruitment pool. This excluded three participants (30, 31 and 34) who were removed from the entire data set due to inconsistencies with condition order. Participant ages ranged from 18 to 31 (M= 25; SD= 3.8). No participants had a neurological or learning disorder.

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2.1.2 Procedure Overview

Each participant was greeted by the experimenter and given a participant information sheet and consent form. After informed written consent was obtained, participants were told that the batch of measures would take approximately 45 minutes to complete and they could withdraw from the study at any time. Each participant began the study by completing the Varieties of Inner Speech Questionnaire (VISQ), followed by the Tower of London task and finally the Card Sorting Task. Participants were split into two categories (high and low) depending on how they scored in the VISQ. They created a unique identification in the VISQ and this was used to identify them in the two measures of executive function. They were told they could take a break between each experimental condition and also at intervals between each experiment. Participants completed all 3 conditions (standard, articulatory suppression and verbalise strategy) for each of the two measures of executive function in one session. The conditions were counter balanced so each appeared 1st 2nd and 3rd an equal number of times. Participants were under no instruction to use or inhibit self-talk in the standard condition. In the articulatory suppression condition participants were asked to repeat the word Monday; following a 60 beats per minute metronome track concurrently with the task. As in the Baldo et al. (2005) and Williams et al. (2012) studies, if participants went silent they were reminded to vocalise the word Monday, if they had to be reminded to repeat the word on 5 separate occasions their data was removed from analysis. In the overt vocalisation condition participants had to vocalise their strategies and were told their speech was only for them and they could not direct their speech towards the experimenter. Participants were given the same order of conditions for both experiments. After completion of measures participants were thanked and received a verbal and written debrief.

2.2 Part 1: Questionnaire

2.2.1 Materials

Varieties of Inner Speech Questionnaire (VISQ) – McCarthy-Jones and Fernyhough (2011).

The VISQ was used to measure the quality and functional properties of participant's inner speech and is the only questionnaire to date that investigates the phenomenological quality of inner speech (McCarthy-Jones and Fernyhough, 2011). It is a self-reported inventory with an 18 item scale. Each item is based on a six point Likert scale (1= certainly applies to me to 6= certainly does not apply to me). There are four subscales: dialogic inner speech consists of 4 items all positively keyed, condensed dialogue consists of 5 items, 3 positively keyed and 2 negatively keyed, other people in inner speech which consists of 5 items all positively keyed, and finally self-evaluative/motivational inner speech which consists of 4 items all positively keyed (for question details see appendix A). For the purpose of this study the two subscales (dialogic and condensed/expanded) were calculated together given the association credited from Fernyhough's (2005; 2008) elaboration and development of Vygotsky's (1987) model. Dialogic items produce scores from 4-24 and condensed dialogue items produce scores from 5-30, combining the two scores together produce low scores of 9 and high scores of 54. A median split classified Participants scoring < 32 as having a low quality of inner speech and participants scoring > 33 as having a high quality of inner speech. Subscales were found to have very good internal reliability (Cronbach's α > .80), moderate/good test–retest reliability (>.60) (McCarthy-Jones and Fernyhough, 2011; Alderson-day et al, 2014).

2.2.2 Procedure

The VISQ questionnaire was administered electronically through Bristol Online Survey (https://www.survey.bris.ac.uk). Participants were made aware that there were 18 short questions that would take approximately 5 minutes to complete.

2.3 Part 2: Experiment 1 – The Tower of London

2.3.1 Materials

A computerized version of the TOL was created strongly following the original apparatus of the task (Shallice, 1982). Computer programing software Opensesame was used to program the experiment. The stimuli was created in Microsoft PowerPoint, saved as a JPEG and reopened and edited in Microsoft Paint. Each image was resized by pixels; horizontal: 950 and vertical: 534 and included two wooden frames each with 3 colored balls (green, blue and red) and 3 differing heights of pegs (holding either one, two or three balls). On the same screen; one image represented the goal state and another image represented the start state. The start state was presented larger than the goal state to emphasise that participants needed to change the start state (see figure 1). The start state stimuli measured wooden frame 8.5 x 1 x 0.5cm (length x width x height), each colored ball 1.75 x 1.5cm (length x height), peg holding one ball 1 x 2.5 cm (length x height), peg holding two balls 1 x 4.5 cm (length x height) and finally peg holding three balls 1 x 6.5cm (length x height). The goal state stimuli measured wooden frame 8.5 x 1 x 0.5cm, each colored ball 0.75 x 0.7cm, peg holding one ball 0.5 x 1.5cm, peg holding two balls 0.5 x 2.5cm and finally peg holding three balls 0.5 x 3.5. The stimuli was presented on Samsung 355V5C 15.6 inch laptop with a screen resolution of 1366 x 768.

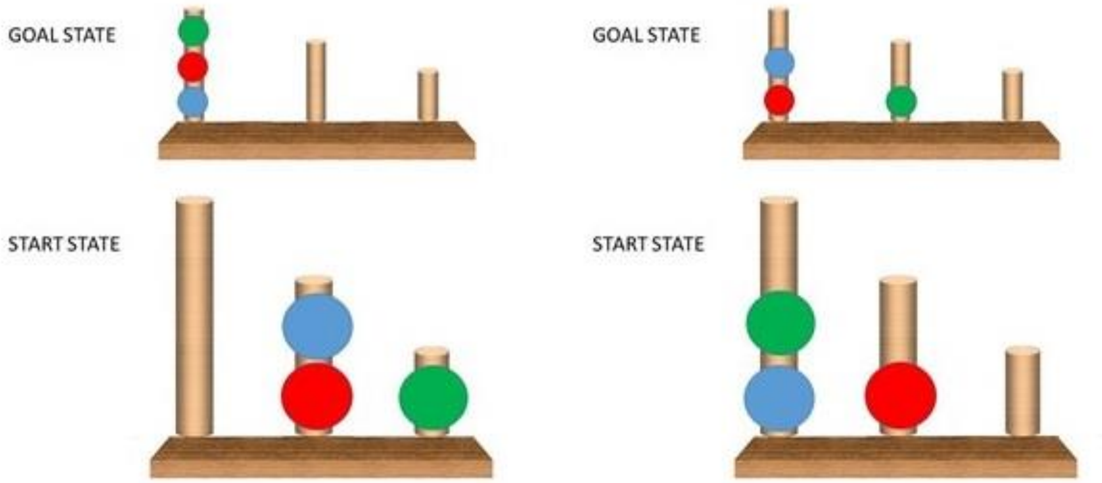

Figure 1: Example of a 3 move (left) and 5 move (right) TOL trial

2.3.2 Procedure

Participants were administered a computerised version of the TOL and were instructed to make the start state look like the goal state in the minimum amount of moves. They were asked to key a number when they had decided how many moves it would take. Participants had to move the balls around in their minds. Whereas other studies have asked participants to physically move one ball at a time and to pre-plan the moves so that they complete each trial in the minimum amount of moves (Wallace et al., 2009; Williams et al., 2012). The rules of the present study were presented to participants and followed the original rules of Shallice (1982), as do the above mentioned studies; the left peg can have 3 balls placed on it, the middle peg can have 2 balls placed on it and the right peg can only have one ball placed on it. Participants were only allowed to move one ball at a time and could only move the top ball. For example, to make the start state look like the goal state in the right sided example in figure 1, participants would need to move the red ball to the far right peg, the green ball onto the middle peg, the blue ball onto the middle peg, the red ball onto the far left peg and finally the blue ball onto the far left peg accounting for a minimum total of 5 moves.

Each condition consisted of sixteen trials; plus two practice trials at the start of each set. Practice trials consisted of the same one and two-move problems with ball colour being changed around in each practice condition. None of the practice trials were presented in the experimental conditions. Each experimental condition consisted of four two-move problems, four three-move problems, four four-move problems and four five-move problems, totaling sixteen trials. No problem appeared in the same condition twice. However, three out of the twelve five-move problems varied in colour. Each colour variation was placed into a condition, so that each condition contained 4 unique five-move problems. No condition contained the same spatial permutation and colour variation. For example, one five-move trial was a colour variation of a five-move problem taken from condition two. The colour variation in the five-move problems was necessary because of a lack of spatial permutations (Fimbel, Lauzon & Rainville, 2009). All trials in each condition were randomized. Each trial was presented at the centre of the screen and after participants had keyed their response a blank screen was shown for 1 second before the next trial was presented. Participants were not told if their response was correct. Participants were given two practices trials at the beginning of each condition before moving onto the experimental trials. After participants completed the first condition they were asked to make the experimenter aware and told they could take a break. They were then given the next condition. This was repeated until all three conditions were completed. It took approximately 25 minutes to complete the task. The data was recorded and saved by Opensesame. After all participant data was collected it was placed into one manageable Microsoft Excel file and analysed using IBM SPSS Statistics 23.

2.3.3 Scoring

Participants scored correctly if they keyed the correct response in relation to the minimum amount of moves needed to complete each trial. The main dependent variable was the difference between the minimum amount of moves needed to complete each set of conditions and the total amount of moves keyed by the participant (Berg & Byrd, 2002). High scores on the TOL indicated excess moves and therefore worse planning ability. The Amount of correct trials in each condition was also measured.

2.4 Part 3: Experiment 2 – The Card Sorting Task

2.4.1 Materials

The CST presents four stimulus cards: single red triangle, two green stars, three yellow crosses and four blue circles (see figure 2). Each card measured 5.5cm x 7.5cm (length x width) and were designed in Microsoft PowerPoint, saved as a JPEG, and reopened and edited in Microsoft paint. Cards were printed and finally laminated. A scoring sheet was developed in Microsoft word (the scoring sheet can be seen in Appendix B).

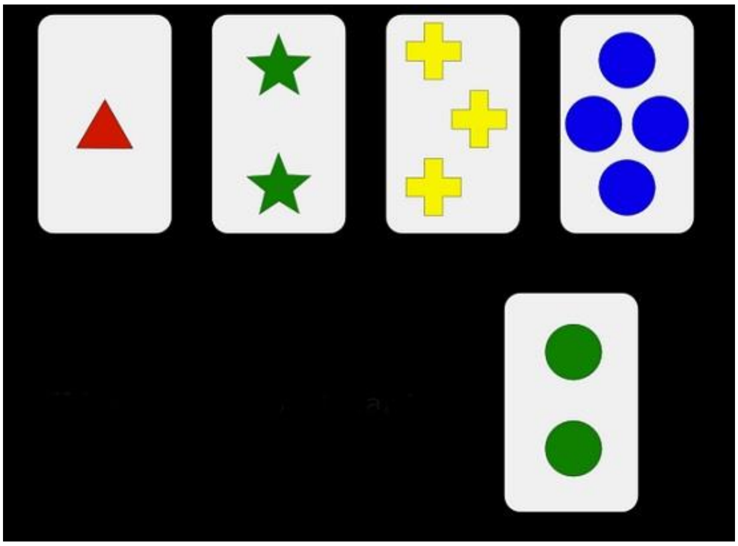

Figure 2: Four stimuli cards (top row) and one of the 48 response cards (bottom)

2.4.2 Procedure

The current experiment administered the manual version of the Modified Card Sorting Task (MCST; Nelson, 1976) which has similarities with the current standard version of the Wisconsin Card Sorting Task (WCST; Heaton, 1981). Participants were presented with 4 stimulus cards and a pack of 48 cards. They were instructed that they would have to match each card from the pack to the stimuli cards and that the experiment had a rule that they had to guess. There were 3 possible matching rules colour, number or shape. They would need to place each card in front of a stimulus card to guess the experimenters rule, they would then be told either ‘correct’ or ‘incorrect’. Participants had to use this feedback to learn the rules of the task. The experimenter explained that from time to time the rule would change, but they would not be told when the rule was to be changed. Participants could take as long as they liked to place a card, however they could not change their mind after the card had been placed in a pile. By the end of the task they would have four piles of cards stacked in front of the 4 stimulus cards. Finally they were told they should attempt to get as many correct responses as possible. Participants were asked if they would like to have the instructions repeated or if they had any questions.

Each condition used 2 packs of 24 cards, making 48 trials, the same two packs of cards were used in all three conditions. All 48 response cards have been designed so that they do not share more than one category with the stimuli card (Nelson, 1976). Categories consist of colour (red, green, yellow and blue), shape (triangle, star, cross and circle) and number (1, 2, 3 and 4). Each category was presented in each of the conditions twice so that 5 set-shifts were present in each condition. No conditions were timed. The first category was decided by the participant, they placed a card down in front of a matching stimuli card (colour, number or shape) and begin the sequence of correct responses. To complete a category a participant would need to place a card in front of a stimuli card 6 correct times. After 6 correct responses the category changed and the participant had to discover the new rule. Each category was presented twice. The task ended after the participant had completed all 6 categories or had used all of the 48 response cards. The experiment took approximately 15 minutes to complete.

2.4.3 Scoring

This experiment used the materials of the MCST (Nelson, 1976). However, it did not use the scoring method proposed by Nelson. The modifications that Nelson made to the standard WCST have been criticised[1]. Instead, this experiment used scoring that was proposed by Heaton (1981). Two out of the sixteen scoring proposals were used in the current study perseverative errors (continuation of an incorrect rule) and percentage correct (percentage of correct trials). The main dependent variable was perseverative errors.

2.5 Ethical Considerations

The British Psychological Society (2015) code of ethics and conduct was used to guide this study. Ethical consent was obtained from Nottingham Trent University's School of Social Sciences ethics committee.

3. Results

3.1 Combined TOL & CST data

The means and standard deviations for experiment type for inner speech quality levels in the three conditions can be found in table 1. A median split was performed on the VISQ data. The data were normally distributed, with skew and kurtosis within limits of +/-2. There was one extreme score that was removed from the data set following outlier detection rules (Hoaglin & Iglewicz, 1987), three participants (30, 31 and 34) were removed from the entire data set due to inconsistencies with condition order, one mean data point was excluded from the data set due to the experimenter recording data inaccurately, three due to participant not understanding instruction and two due to participant completing two sets under one condition. Excess moves from the TOL and perseverative errors from the CST were z-scored because they have non-comparable measures. The raw data

[1] Zubicaray and Ashton (1996) claim that Nelson's MCST eliminates the requirement that participants detect and respond to shifts in categories. This occurs because the MCST informs participants that the rule has changed after 6 successful responses. If the current experiment adopted this scoring method then it would not have been measuring cognitive flexibility effectively.

scores were placed into Microsoft Excel and the 3 conditions (standard, articulatory suppression and overtly verbalise) of each experiment were placed into 3 separate columns and were transformed into z-scores. A 3 x (condition order: three levels) x 2 (inner speech quality level: high and low) x 3 (condition: standard, articulatory suppression and overtly verbalise) x 2 (experiment: Tower of London and Card Sorting Task) mixed designed ANOVA was performed on the data, with order effect and inner speech quality level as the between subject variables and condition and experiment as the within subjects variables. There was a significant effect of inner speech quality level with low inner speech quality performing better than high inner speech quality $F(1, 21) = 4.90$, $p = .038$. The non-significant effect of experiment type (Tower of London/Card Sorting Task), $F<1$, was expected because the Z score transformation would have forced both levels to have the same mean of zero. There was no effect of condition, $F(2, 42) = 2.01$, $p=.148$. There was an interaction between experiment and order effect, $F(2, 21) = 3.93$, $p = .036$, condition and condition order, $F(4, 42) = 3.22$, $p = .022$, and a triple interaction between experiment, condition and condition order, $F(4, 42) = 9.85$, $p < .001$. There was no other statistically significant effects involving condition order, $F<1$ (see Appendix C) for a separate analysis of each participants first test in order to see what would happen if order was not a factor). There was an interaction between experiment and inner speech quality levels, $F(1, 21) = 9.13$, $p = .007$, and an interaction between experiment and condition $F(2, 42) = 7.57$, $p = .002$, finally a marginal interaction between condition and inner speech quality levels, $F(2, 42) = 2.54$, $p = .091$, all of which are explored below. Qualitatively similar patterns were found when analysing the percentage correct data (see Appendix D).

Table 1: Mean, and standard deviations in parenthesis for experiment type (Tower of London/Card Sorting Task) with inner speech quality levels (high/low) for three levels of condition (standard, articulatory suppression and overtly verbalise)

	Tower of London		Card Sorting Task	
Inner Speech Quality Levels	High	Low	High	Low
Standard	2.44(1.83)	2.27(2.2)	1.72(1.74)	.43 (1.1)
Articulatory Suppression	3.44 (2.34)	3.55(3.41)	1.44 (1.46)	.21 (.43)
Overtly Verbalise	3.0 (1.55)	3.82 (1.4)	.44 (.86)	.00 (.00)

3.2 TOL excess moves data

The Tower of London experiment was analysed separately from the main analysis. There was one extreme score that was removed from the data set following outlier detection rules (Hoaglin & Iglewicz, 1987). Three mean data points were excluded from the data due to participants not understanding instruction. Two due to participant completing two sets under one condition. A 2 (inner speech quality level: high or low) x 3 (condition: standard, articulatory suppression and overtly verbalise) mixed designed ANOVA was performed on the Tower of London's excess moves data and were analysed without z-scores, with inner speech quality level as the between subject variable and condition as the within subjects variable (see Figure 3, for means). There was no main effects between high or low inner speech quality, $F<1$, no main effect between standard, articulatory suppression and verbalisation conditions, (F (2, 50) = 2.09, p =.135), and no interaction between inner speech quality level and conditions, $F<1$.

3.3 CST perseverative errors data

Similarly to the Tower of London analysis; the Card Sorting Task experiment was analysed separately from the main analysis. One mean data point was excluded from the data set due to the experimenter recording data inaccurately. A 2 (inner speech quality level: high or low) x 3 (condition: standard, articulatory suppression and overtly verbalise) mixed designed ANOVA was performed on the Card Sorting Tasks perseverative errors data and were analysed without z-scores, with inner speech quality level as the between subject variable and condition as the within subjects variable (see figure 3, for means). There was a main effect of inner speech quality levels, low quality of inner speech produced less errors than those with high quality of inner speech, F(1, 30) = 17.56, p =.007. There was a main effect of condition, F(2, 60) = 9.82, p <.001, follow up paired sample t tests showed that, less errors were produced in the verbalising condition than the standard condition (t (31) = 3.93, p < .001), less errors were produced in the verbalising condition than the articulatory suppression condition (t (32) = 3.87, p < .001), and there were no differences between the standard and articulatory suppression conditions (t (31) = 1.28, p = .221). There was a marginal interaction between inner speech quality levels and condition, F(2, 60) = 2.85, p =.066, follow up independent sample t tests were ran on the basis of the relevance to predictions - it was deemed acceptable on balance. T tests results demonstrated that participants with low inner speech quality produced less errors in the standard condition than participants with high inner speech quality (t (30) = 2.43, p = .021), participants with low inner speech quality also produced less errors in the articulatory suppression condition than participants with high inner speech quality, (t (31) = 2.99, p = .005), and there was a marginal difference in errors for the overtly verbalising condition, participants with low inner speech quality produced marginally less errors than participants with high inner speech quality, (t (31) = 2.01, p = .054).

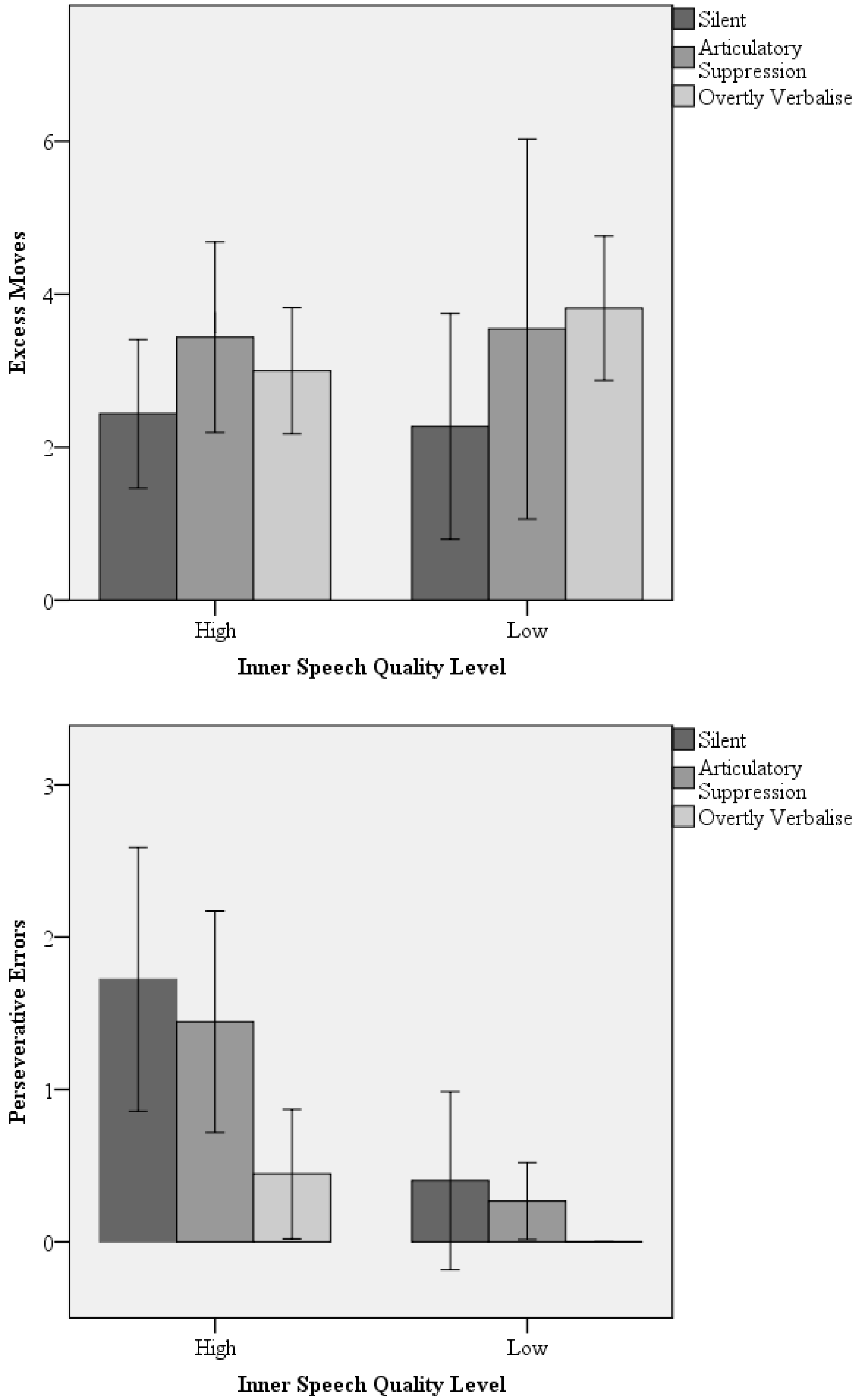

Figure 3: (bottom: Card Sorting Task) Perseverative errors for inner speech quality levels (high/low) for three levels of condition (standard, articulatory suppression and overtly verbalise). Error bars 95% CI. (Top: Tower of London) Excess moves for inner speech quality level (high/low) for three levels of condition (standard, articulatory suppression and overtly verbalise). Error bars 95% CI.

4. Discussion

The study was designed to investigate high and low inner speech quality and how this influences executive functions. The present study has demonstrated that inner speech quality levels influence some executive functioning but not others. It was found that inner speech levels did not have a central role in the Tower of London task. In contrast, high levels of inner speech were detrimental to task performance in the Card Sorting task; participants with low inner speech quality produced significantly better scores on standard, articulatory suppression and overtly verbalising conditions than participants with high inner speech quality. Finally, there was an effect of condition in the Card Sorting Task but not the Tower of London; overtly verbalising produced better scores than both articulatory suppression and standard conditions. Therefore the present study has demonstrated that inner speech is not a domain-general tool and instead operates for selective executive functions.

The perseverative errors from the TOL task indicated that participants with high and low inner speech quality performed similarly when completing the task in the standard condition. This has implications for Fernyhough's (2008) dialogic framework theory as he proposed that planning – a higher mental function - would benefit from inner speech. In accordance with this; higher levels of dialogic inner speech would allow for multiple perspectives to be held in the mind at one time, which would therefore enable a person to become 'unstuck' in a set (Fernyhough, 1996, 2008) and benefit a task such as the Tower of London. Furthermore, the standard condition results do not support Fernyhough's private speech concept. As noted previously, Wallace et al. (2009) did not specify the definition of 'standard' condition, and this left open the interpretation as to whether or not participants utilised private speech, which is regarded as a tool that can benefit cognitively demanding tasks (Duncan & Tarulli, 2009). Therefore, the current study addresses this and supports the notion that private speech was not beneficial as there were no significant differences between participants with high and low inner speech quality. A correlational study investigated the influence of private speech on four executive function tasks, one being the Tower of London, and found that private speech usage was lowest in the tower task (Blaker, 2016) indicating that private speech is not particularly relevant to the Tower of London task. Furthermore, findings from Cheetham, Rahm, Kaller and Unterrainer (2011) indicate that TOL is not verbally mediated in adults and is instead mediated by the visuospatial cognitive modality. This explains the lack of difference in performance between those with high and those with low inner speech quality in standardised conditions.

It was hypothesised that articulatory suppression would have a detrimental effect on participants with high inner speech quality in the TOL. However, results indicate a non-significant effect on neither high nor low inner speech quality, suggesting that planning is not verbally mediated. In contrast, the results from Lidstone (2010), Wallace et al. (2009) and Williams et al. (2012) all found that articulatory suppression effected typically developing individuals indicating that planning is verbally mediated in childhood, adolescence and adulthood. Whilst the studies utilised similar methodology, the age of participants differed, which could account for the difference in results. Lidstone (2010) investigated planning in middle childhood whereas the current study investigated planning in adults. Consequently, it could be suggested that there is a shift away from verbally mediated strategies between middle childhood and adulthood for planning. Additionally, the extra cognitive load that was placed on the participants working memory could further qualify the differences between the two studies. It has been established that verbal and visual working memory capacity gradually increases throughout the lifespan until around the age of 15 where it reaches adult levels (Alloway, Gathercole & Pickering 2006). Therefore, it could be argued that articulatory suppression did not affect adults in the current study because they were able to retain more information within their visual working memory. In contrast, the children in Lidstone's et al. (2010) study would have been affected by articulatory suppression due to planning being verbally mediated in childhood (Vygotsky, 1987; Al-Namlah, 2006) and the possible interaction with capacity limitations in a child's verbal working memory (Alloway, Gathercole & Pickering 2006). The findings from the current study therefore support Baddeley and Hitch's (1974) multicomponent model. They proposed that the phonological loop is a subcomponent of working memory that aids with rehearsal and storage of verbal information and is regarded as having only a representational role in executive functioning. The phonological loop is interfered with by the use of articulatory suppression. Therefore, if a task relies on inner speech for successful completion then applying articulatory suppression to the primary task should significantly impair ability. However, the current studies TOL task failed to demonstrate any effects of articulatory suppression on participants with high or low inner speech quality levels and therefore supports the theory of inner speech having a representational role in executive functioning.

In support of the hypothesis no significant effects were found between participants with high or low inner speech quality on the overtly verbalising condition in the Tower of London task and support the findings of Harvey et al. (2009). Therefore adapting the Tower of London in the current study in an attempt to increase its difficulty did not benefit participants with low inner speech quality. This indicates that overly verbalising only benefits particular executive functions and not the actual difficulty of a task. It can be concluded that planning is not mediated by overtly verbalising. This result could be interpreted to contradict Fernyhough's dialogic thinking framework (2005; 2008) as it could be argued that overly verbalising should assist with task difficulty and should regulate behaviour, a finding not supported by the current study (Fernyhough & Fradley, 2005; Stratta et al., 1996).

The Card Sorting Task indicated that the standard condition was benefited by participants with low inner speech quality and contradicts the findings of Russell-Smith et al. (2013). This unexpected result could be explained by the influence of another mode of processing, namely – visuospatial. Participants with high quality of inner speech may have attended to a specific task element not compatible with inner speech, such as attention to visual processing modality. It could be argued that participants with high inner speech quality attempted to compete with another modality for representation within the task (Tsotsos et al., 1995). This creates competition within the 'cortical real estate' (Franconeri, Alvarez & Cavanagh, 2013) which is mapped for the specific executive function, cognitive flexibility. Therefore, the correct mode of processing cannot function correctly due to interference, and perseverative errors are made. The competition concept is supported by Franconeri et al. (2013) who studied flexible cognitive resources. They claim that the brains cognitive systems

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(attention, working memory) each have capacity limits and when competition occurs within the 'cortical real estate' a destructive interaction can occur. Therefore, it could be said that participants with high inner speech quality attempt to use a sub-optimal strategy due to their bias towards inner speech that can cause problems for executive functions such as cognitive flexibility.

It was hypothesised that articulatory suppression would have a detrimental effect on participants with high inner speech quality in the CST. The results supported the hypothesis - participants with high inner speech quality were significantly affected by articulatory suppression in comparison to participants with low inner speech quality. This suggests that participants with high inner speech quality relied on inner speech to mediate cognitive flexibility more than participants with a low inner speech quality. The results support the findings of Russell-Smith et al. (2013) and Baldo et al. (2005) and also the findings from previous TOL studies (Wallace et al., 2009; Williams et al,, 2012; Lidstone et al,, 2010) investigating articulatory suppression on planning. In contrast, participants with high inner speech quality were unaffected during the articulatory suppression condition in the Tower of London task demonstrating that planning is not mediated by inner speech. Therefore, the disparity in articulatory suppression results between the participants with high inner speech quality in the current studies CST and TOL suggest that inner speech has separable trajectories for specific executive functions and contradict the findings of Fatzer and Robers (2012) and Al-Namlah (2006). They concluded that inner speech is a domain general tool that is verbally mediated in cognitive functions from the age of seven onwards. In addition, the articulatory suppression results for participants with high inner speech quality on the CST supports Vygotsky (1987) and Fernyhough (2005, 2008) theories that inner speech is involved in cognitive flexibility. However, when considering the results from both the CST standard condition and the articulatory suppression condition, it could be suggested that participants with low inner speech quality benefited in comparison to participants with high inner speech quality, which provides evidence against Vygotsky (1987) and Fernyhough (2005, 2008), as these theories highlight the importance of inner speech on executive functioning.

The findings for overtly verbalising on the CST demonstrated that participants with low inner speech quality performed significantly better than participants with high inner speech quality. This finding supports Russell-Smith et al's. (2013) suggestion that typically developing children benefit from overtly verbalising. These two studies as a collective develop a view that overtly verbalising is beneficial for typically developing individuals with low inner speech quality over a portion (10-25 years) of the lifespan. Further studies need to consider if this is different for older populations. In addition, the current studies results reinforce the findings of Perry (2001) supporting the idea that overtly verbalising significantly benefits not only atypical populations (populations with autism or schizophrenia) who are associated with having deficits, dysfunctions and even absents of inner speech (for a review see Hill 2004; Allen, Aleman & McGuire, 2007), but also typical populations with low levels of inner speech. However, it is necessary to consider that fewer errors were produced in the overtly verbalising condition than the articulatory suppression and standard condition in the CST, demonstrating that participants with high and low inner speech quality benefited from overtly verbalising. This could be attributed to decreases in distractibility on tasks such as the CST that requires greater concentration (Meichenbaum & Cameron, 1973) and overtly verbalising could activate cognitive resources that are not recruited automatically when using inward modes of processing (Robinson, Gray, Ferrier & Gallagher, 2016).

A limitation of the current study is the median split that was performed on the varieties of inner speech questionnaire. Turning continuous variables into categorical variables reduces statistical power and increases the risk of type I errors (Altman, 2006). Therefore future research should investigate using a correlational design to challenge the results of the current study. In addition future research needs to be directed at understanding inner speech quality and how it influences specific executive functions over the lifespan of typically developing individuals. A richer understanding of this could provide fundamental information on how individuals can maximise their goal-directed behaviour. The findings also implicate the need to further investigate verbal thinking interventions that are directed at those with autism and schizophrenia (Kenworthy et al., 2013; Harvey et al., 2009). Future research should aim to control for separate cognitive modalities in an attempt to understand how these can reduce cognitive deficits that could help develop interventions designed to target specific executive functions. This could allow atypical populations to maximise their goal-directed behaviour.

5. Conclusion

This study is the first to investigate the influence of inner speech quality in typically developing adults on measures of executive functions; quantifiably measuring the effects of standard, articulatory suppression and overtly verbalising conditions. The findings demonstrate that planning is not dependent on inner speech, however cognitive flexibility is negatively affected by high quality levels of inner speech in typically developing adults. These results are essential for understanding the role of inner speech in supporting complex executive functions. Furthermore, inter-individual variation is evident in how inner speech quality is utilised for executive functioning in adulthood. There is a need for a better understanding of inner speech quality and its cognitive development shifts between childhood, adolescence, adulthood and old age.

Further to this, the results on the two measures of executive function suggest that inner speech has separable trajectories for specific executive functions. This finding advocates the need to continue this area of study with a range of executive functioning tasks to further investigate the possible interactions between inner speech quality and executive functions. Such findings are of importance to understanding the cognitive development of inner speech for typical and atypical populations that will help to advance and maximise performance and interventions.

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"You only get out what you put in"

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Appendix A. Varieties of inner speech questionnaire (VISQ)

Items on the Varieties of Inner Speech Questionnaire (VISQ), and their factor structure:

Item	Factor loadings			
	Factor 1 (Dialogic Inner Speech)	**Factor 2 (Condensed Inner Speech)**	**Factor 3 (Other People in Inner Speech)**	**Factor 4 (Evaluative/Motivational Inner Speech)**
I think to myself in words using brief phrases and single words rather than full sentences	.09	**.78**	.03	.05
When I am talking to myself about things in my mind, it is like I am going back and forward asking myself questions and then answering them	**.80**	−.02	−.04	−.10
I hear the voice of another person in my head. For example, when I have done something foolish I hear my mother's voice criticising me in my mind	.09	.10	**−.79**	−.09
I experience the voices of other people asking me questions in my head	.23	.02	**−.73**	−.08
I hear other people's voices nagging me in my head	.05	.03	**−.81**	−.02
My thinking in words is more like a dialog with myself, rather than my own thoughts in a monolog	**.76**	.04	.01	.01
I think to myself in words using full sentences	−.21	**.76**	−.03	−.07
My thinking to myself in words is like shorthand notes, rather than full, proper, grammatical English	.03	**.77**	.10	.03
I think in inner speech about what I have done, and whether it was right or not	.01	−.11	−.02	**.66**
When I am talking to myself about things in my mind, it is like I am having a conversation	**.78**	−.08	−.01	.15

Item	Factor loadings Factor 1 (Dialogic Inner Speech)	Factor 2 (Condensed Inner Speech)	Factor 3 (Other People in Inner Speech)	Factor 4 (Evaluative/Motivational Inner Speech)
with myself				
I talk silently to myself telling myself to do things	.29	.12	.05	**.61**
I hear other people's actual voices in my head, saying things that they have never said to me before	−.10	−.09	−**.75**	.07
I talk back and forward to myself in my mind about things	**.70**	−.10	−.08	.27
My thinking in words is shortened compared to my normal out-loud speech. For example, rather than saying to myself things like 'I need to go to the shops', I will just say 'shops' to myself in my head	.06	**.79**	−.09	.11
If I were to write down my thoughts on paper, they would read like a normal grammatical sentence	−.10	**.74**	−.09	−.14
I hear other people's actual voices in my head, saying things that they actually once said to me	−.17	−.01	−**.79**	.17
I talk silently to myself telling myself not to do things	.18	.07	−.05	**.73**
I evaluate my behaviour using my inner speech. For example I say to myself, "that was good" or "that was stupid"	−.15	.01	−.04	**.88**

Appendix B: Scoring sheet for Card Sorting Task

Participant reference: Order of Conditions:

Tria l	Rule	R	PE	EE	DE	Trial	Rule	R	PE	EE	DE
1	C S N					25	C S N				
2	C S N					26	C S N				
3	C S N					27	C S N				
4	C S N					28	C S N				
5	C S N					39	C S N				
6	C S N					30	C S N				
7	C S N					31	C S N				
8	C S N					32	C S N				
9	C S N					33	C S N				
10	C S N					34	C S N				
11	C S N					35	C S N				
12	C S N					36	C S N				
13	C S N					37	C S N				
14	C S N					38	C S N				
15	C S N					39	C S N				
16	C S N					40	C S N				
17	C S N					41	C S N				
18	C S N					42	C S N				
19	C S N					43	C S N				
20	C S N					44	C S N				
21	C S N					45	C S N				
22	C S N					46	C S N				
23	C S N					47	C S N				
24	C S N					48	C S N				

R = Perseverative response E = Perseverative error

EE = Efficiency error DE = Distraction error

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Appendix C: Separate analysis of each participant's first test in order to see what would happen if order was not a factor

Excess moves and perseverative errors Data was z-scored on participants first test data only. The data was z scored because they have non-comparable measures. The raw data scores were placed into Microsoft Excel and the 3 conditions (standard, articulatory suppression and overtly verbalise) of each experiment were placed into 3 separate columns and were transformed into z-scores. Data was z-scored based on the mean and standard deviations of the participant's first condition. A 2 (inner speech quality level: high and low) x 2 (experiment: tower of London and card sorting task) x 3 (condition: standard, articulatory suppression and overtly verbalise) mixed designed ANOVA was performed on the data, with inner speech quality level and condition as the between subject variable and experiment as the within subjects variable. There was a significant effect of inner speech quality level with low quality of inner speech performing better than high quality of inner speech, F (1, 23) = 5.75, p <.025. The non-significant effect of experiment type (Tower of London/card sorting task), F <1 was expected because the Z score transformation would have forced both levels to have the same mean of zero. There was an interaction between inner speech quality level and condition, F (2, 23) = 4.03, p <.032. There was also an interaction between experiment and condition F (1, 23) = 8.32, p <.002. There was no interaction between experiment and inner speech quality level, F (1, 23) = 2.15, p >.157 and no triple interaction F <1.

Appendix D: Percentage correct data

Percentage correct data was z-scored because they have non-comparable measures. The raw data scores were placed into Microsoft Excel and the 3 conditions (standard, articulatory suppression and overtly verbalise) of each experiment were placed into 3 separate columns and were transformed into z-scores A 3 x (condition order: three level) x 2 (inner speech quality level: high and low) x 3 (condition: standard, articulatory suppression and overtly verbalise) x 2 (experiment: Tower of London and Card Sorting Task) mixed designed ANOVA was performed on the data, with order effect and inner speech quality level as the between subject variables and condition and experiment as the within subjects variables. There was a significant effect of inner speech quality level with low quality of inner speech performing better than high quality of inner speech F (1, 21) = 8.68, p =.007. The non-significant effect of experiment type (Tower of London/card sorting task), F<1 was expected because the Z score transformation would have forced both levels to have the same mean of zero. There was a significant effect of condition, F (2, 44) = 3.66, p<*.001*. There was an interaction between experiment and order effect, F (2, 22) = 4.02, p =.033, and a triple interaction between experiment, condition and order effect, F (4, 44) = 4.98, p =.002. There was a non-significant interaction between inner speech quality level and order effect F (1, 22) = 1.61, p =.223, condition and inner speech quality level, F (4, 44) = 1.89, p =.092. There was a non-significant quadruple interaction between experiment, condition, inner speech quality level and condition order, F (4, 44) = 2.14, p =.092. There was no other statistically significant effects involving order effects F <1. There was an interaction between experiment and condition F (4, 44) = 14.76, p <.001, condition and inner speech quality level, *F* (2, 44) = 6.03, *p* =.005. Finally, no significant differences were found between experiment and inner speech quality level, *F* (1, 22) = 2.58, *p* =.123

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