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**Title: The Digit Span Backwards Task: Verbal and Visual Cognitive Strategies in Working Memory Assessment**

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# The Digit Span Backwards Task: Verbal and Visual Cognitive Strategies in Working Memory Assessment


## Summary

The "digit span backwards" (DSB) is the most commonly used test in clinical neuropsychology to assess working memory capacity. Yet, it remains unclear how the task is solved cognitively. The present study was conducted to examine the use of visual and verbal cognitive strategies in the DSB. Further, the relationship between the DSB and a complex span task, based on the *Simultaneous Storage and Processing* task (Oberauer et. al., 2003), was investigated. Visualizers performed better than verbalizers in the dual task condition ($r_{PB}$ = .23) only when the relevant digits were presented optically. Performance in the DSB correlated only weakly with the complex span task in all conditions (all $\tau \leq .21$). The results indicate that the processing modality is determined by the preference for a cognitive strategy rather than the presentation modality and suggest that the DSB measures different working aspects than commonly used experimental working memory tasks.


***Key words:*** Cognitive Strategy, Cognitive Style, Digit Span Backwards, Working Memory Assessment

## 1. Introduction

The term working memory has been shaped through the work of Baddeley and Hitch (1974) who proposed one of the most influential working memory models in the last century. The concept of working memory describes the temporary storage and manipulation of information, as necessary for complex cognitive tasks like reasoning or language comprehension (Baddeley, 1992). The model includes a visuospatial sketchpad and a phonological loop, responsible for visual and verbal working memory tasks, respectively.

Since working memory is partially defined by its limited capacity (Bireta et al, 2010), several paradigms have been developed to test for inter-individual differences. In clinical neuropsychology, the “digit span backwards” task (DSB) remains the prevalent approach to assess working memory capacity (see Ramsay & Reynolds, 1995). In line with this notion, several psychological test batteries, such as the “Wechsler Adult Intelligence Scales” (WAIS; Wechsler, 2008), include the test in order to assess this facet of cognitive capacity.

In most experimental contexts, however, working memory performance and functioning are assessed with different tasks, like the *n-back task* (see Owen, McMillan, Laird, & Bullmore, 2005) or complex span tasks (see Redick et al., 2012). Only a few exceptions are provided by Dunn, Gaudia, Lowenherz, and Barnes (1990) or Hoshi et al. (2000). A thorough investigation of the DSB task is therefore necessary to close the gap between the term working memory in clinical and experimental contexts.

One of the most influential models in current experimental working memory research has been proposed by Oberauer, Süss, Schulze, Wilhelm, and Wittmann (2000). Oberauer et al. (2003) define their model of working memory as a “set of limiting factors for performance in complex cognitive tasks”. They define two facets of an overall working memory structure: (1) content and (2) function. The content facet comprises verbal-numerical material and spatial material while the functional facet is divided into the components “coordination”, “supervision”, and “simultaneous storage and processing”. However, evidence for the subdivision within the content facet between verbal-numerical and spatial working memory has been found to be rather weak (see Oberauer et al., 2003).

Within the functional facet, the “storage and processing” component is measured by complex span tasks, which are widely used in working memory research and combine the storage aspect of a simple span task with an intercalated processing task (e.g., Kane et al., 2004; Redick et al., 2012). The tasks require the participant to memorize material and reproduce it after a simple processing task, such as, for example, reading a sentence. These complex span tasks are viewed as examples of the dual task (Oberauer et al., 2003) and are considered to asses a fundamental component of working memory, even though they have been found to correlate only weakly with tasks, such as the *n-back* task, that are from other working memory paradigms (Jaeggi et al., 2010; Kane, Conway, Miura, & Colflesh, 2007; Li et al., 2008).

In addition, it is important to consider which cognitive processes can be used to solve the DSB. In the present article, processing is defined as the transformation of information necessary to invert the digit span. In order to orally repeat a digit span backwards, one can either verbalize the perceived digits and repeat them silently or visualize them internally and read them backwards (Dunn et al., 1990).

The choice of a preferred kind of cognitive processing has mostly been named, “strategy” or “style” in the literature (see Riding & Cheema, 1991, for an overview). The term “style” is usually refers to more rigid and stable subdivisions while “strategy” describes the more specific choice when facing a situation or task. Since the choice of a cognitive approach to an experimental task represents a rather specific action, it will be referred to as “cognitive strategy” in this article.

The most prominent subdivision within the group of all persons using preferred cognitive strategies is made between verbalizers and visualizers (Rayner & Riding, 1997). According to Bartlett (1932), visualizers tend to make use of internal imagery as a memorization strategy, while verbalizers prefer articulatory techniques, such as inner rehearsal. Obviously, these two strategies correspond neatly to the two working memory subsystems proposed by Baddeley and Hitch (1974), namely the visuospatial sketchpad and the phonological loop, respectively.

Further elaborating on the interdependencies of verbal and visual memory subsystems, Paivio (1971) postulated possible coding of optical or acoustical information into a verbal or a visual memory system in his *Dual-Coding-Theory* of sensory processing. The theory describes basic psychological mechanisms, specialized in the processing of visual and phonological information. Within this framework, verbal representations are processed in a sequential manner while non-verbal information can be represented simultaneously to create, for example, a complex image. Importantly, the tendency and the capacity to use imagery vary strongly between individuals (Clark & Paivio, 1991) and might, due to possible verbal and visual processing of digits and numbers (Paivio, 1991), thus have a significant impact on the processing of digit spans. Regarding the automaticity of coding mechanisms, Penney (1989) stated that optical stimuli – in addition to being coded visually – are automatically translated into phonological code if they can be verbalized. The findings clearly point towards the possibility of multiple coding as well as the translation from verbal to visual code and vice versa. This notion obviously holds for numbers, because they are easy to process visually as well as verbally.

Now, which factors determine if the stimulus information is processed visually or verbally? Several authors assumed that the presentation mode is critical for visual or verbal processing (e.g., Penney, 1989; Suchan et al., 2006). Crottaz-Herbette, Anagnoson, and Menon (2004) found cortical areas to be related to verbal working memory operations to be inhibited during the processing of optically presented working memory tasks. Acoustical presentation, on the other hand, resulted in inhibition of areas related to visual working memory processing. Other authors, however, reported contradictory results (e.g., Cowan, Saults, & Brown, 2004; Schumacher et al., 1996). Schumacher et al. found an almost complete overlap of the areas involved in working memory tasks presented optically and acoustically. A plausible explanation for this discrepancy lies in the possibility of internal recoding: neither Crottaz-Herbette et al. nor Schumacher et al. controlled for internal translation of the externally presented stimulus information into a different modality. Notably, Dunn et al. (1990) reported visual processing in several subjects even though the digit span was presented acoustically and Hoshi et al., (2000) even noted recoding of acoustically presented material into a visual representation to be a “fruitful strategy” to improve performance in the digit span backwards test.

Thus, the presentation mode may not be the crucial factor determining the processing modality when recoding into a different working memory sub-system is possible. This suggestion may help to better understand the contradictory results obtained by Crottaz-Herbette et al. (2004) and Schumacher et al. (1996), regarding neural correlates of working memory processes: Since Schumacher et al. used a *3-*

*back task* involving letters, the participants may well have visually imagined the acoustically perceived letters and vice versa. If the presentation modality is confounded with the dominating processing modality, the results are prone to be polluted with the application of different cognitive strategies.

Also, insight into different strategies used during working memory processing may have several implications for clinical assessment: future research could build on the possibility of strategy-use and investigate whether poor test performance in the DSB may be attributable to application of a sub-optimal strategy instead of a global working memory deficit.

The present study aims at investigating the differences in performance between visualizers and verbalizers in the DSB with regards to the presentation mode. Besides simple optical and acoustical presentation, a dual task involving parallel optical and acoustical presentation is applied in order to occupy the visual and the verbal processing channels at the same time and, thus, prevent recoding of the presented information from one modality into the other (similar to the dual tasks applied by Fogarty and Stankov, 1989, to investigate performance in competing tasks). It is hypothesized that performance differences between visualizers and verbalizers, depending on the presentation mode, are observable only in the dual task, due to the prevention of recoding. The experimental working memory task *Simultaneous Storage and Processing* is used to clarify the relationship between the clinically applied DSB and an experimental working memory test. This task was chosen because it is well-founded in the influential working memory model by Oberauer et al. (2000) and fits within the framework of Baddeley and Hitch (1974). Baddeley (1992) even thought simultaneous storage and processing to be one of the most fundamental functions of working memory.

## 2. Methods

### 2.1 Sample

117 native German-speaking university students (64 female) participated in the present study (age range 18 – 30 years). For their participation, the subjects received 15 Euros and a written confirmation of participation, exchangeable for course credit.

### 2.2 Materials

All tests were conducted on a Dell E6510 personal computer with an Intel 2.53 GHz central processing unit, 4.00 GB random access memory and an Nvidia NVS 3100M graphics adapter.

#### 2.2.1 Assessment of working memory

Working memory capacity was assessed using the test *Simultaneous Storage and Processing* (based on Oberauer et al., 2003). Subjects were required to memorize words, numbers, or patterns, presented in tachoscopic form. In a subsequent two-alternative-forced-choice distractor task, the participants had to repeatedly assign verbal, numerical, or spatial material (paralleling the material of the respective memory task) to a category. The three conditions were presented in blocked manner: the verbal condition was presented first, the numerical condition second, and the spatial condition last. In the verbal condition, the two categories were “plant” vs. “animal” for a displayed word, in the numerical condition “even number” vs. “uneven number”, and in the spatial condition an arrow had to be categorized into pointing “upwards” or downwards”. The distractor task lasted five seconds, after which the subjects were asked to recall the previously memorized material. Each type of material was presented for 15 trials. In the verbal condition, the number of items to remember increased from three to seven (three times each level of memory load), in the numerical condition from four to eight (three times each level), and in the spatial condition from two to four (five times each level). Every trial in which all items were remembered correctly was scored with one point. The distractor task was not part of the scoring procedure, as recommended by Oberauer et al. (2003). However, it was checked for random answering patterns in order to rule out that subjects focused solely on the memorization task.

### 2.2.2 Assessment of digit span backwards performance

The visual stimulus material was presented black digits in Arial font at a visual angle of 3° in height against a white background for all participants. The acoustically presented digits were spoken by a neutral computer voice. The acoustical presentation time of each digit was set to one second, as was the optical presentation time. Half of the participants faced the acoustical presentation first and the optical presentation second, the other half vice versa. Also, the order of the digit spans was randomized between the subjects. No digit appeared more than once in one digit span. The keyboard of the computer was covered in order to prevent the subjects from using the number keys to assist memorization.

### 2.2.3 Assessment of cognitive strategies

The subjects received a questionnaire. After several general questions[1], that were intended to provide qualitative information about possible strategies as well as lead the participants towards a clear picture of how they solved the task, the participants had to decide in a two-alternative-forced-choice question whether they remembered the digits more visually or more verbally. The forced-choice question

[1] Two exemplary questions are: „Please describe as clearly as possible how you attempted to remember the digits!“ or “If you applied a certain strategy, please describe how you did this”.

was used to categorize the participants into verbalizers and visualizers for the analysis.

**2.3 Procedure**

The testing was performed in two separate sessions in a university laboratory under comparable conditions. In the first session, working memory capacity was assessed with the experimental working memory task in group-sessions of up to five participants on individual personal computers.

Performance in the DSB and the use of cognitive strategies were assessed individually in a second session. In order to assess the digit span baseline, the participants were presented with 18 digit spans consisting of four to six digits which they had to repeat in reversed order right after the presentation. Nine of the digit spans were presented optically, nine acoustically.

Next, 20 dual (i.e., synchronous) presentations of optical and acoustical digit series were conducted. During each presentation, the optical and acoustical series differed regarding the digits, yet were of equal length (4 – 6 digits) in order to make them comparable to the sequence length of the baseline.

After the presentation, the participants were asked to repeat either the

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Insert Figure 1 about here

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optically or the acoustically presented digit series in reversed order. By telling the subjects only after the presentation which digit series had to be repeated, it was ensured that both digit spans had to be remembered. Again, the order of the digit series was randomized between the subjects, as was the order of series to be repeated with regards to the presentation mode (i.e., either the acoustical or the optical series). In total, each subject had to repeat 10 acoustical and 10 optical series in the dual task condition. Figure 1 depicts an overview of the DSB testing session.

### 2.4 Analysis

Independent sample *t*-tests were conducted to assess the differences in performance between subjects who described themselves as verbalizers and those who stated to have used visualization. The decrease in performance between the single task and the dual task was calculated for each participant individually: the percentage of correctly reproduced digit series in the dual task was subtracted from the percentage of correctly reproduced digit series in the dual task. Therefore, high values indicate a strong decrease between the single and the dual task. Effect sizes are displayed in terms of Hedge's *g* ($g_{Hedges}$) for within group comparisons and point-biserial correlations ($r_{PB}$) for between group comparisons. In addition, Kendall's *Tau* ($\tau$) rank correlation coefficients were calculated to investigate the relationship between working memory and the DSB. When required, the significance levels were adjusted by applying *Bonferroni* correction to a total alpha-level of .05. All tests were run two-tailed unless stated otherwise.

## 3. Results

### 3.1 Sample

Two subjects had to be excluded from the analysis, one due to a lack of participation during the tests and another one because he did not report his cognitive strategy in the questionnaire.

**3.2 Cognitive strategies**

*n* = 23 of the subjects reported to have used a visualization strategy in the while *n* = 92 participants relied on a verbalization strategy. No participant reported to have used none of the two strategies.

**3.3 DSB performance**

**3.3.1 Single vs. dual task condition**

Performance decreased significantly between the single and the dual task condition ($t(114) = 31.25$; $p < .01$, one-tailed; $g_{Hedges} = 3.01$), indicating that the dual task made it more difficult for the participants to remember the required digits.

**3.3.1 Acoustical vs. optical presentation**

Statistically, it does not make sense to compare the difficulties of acoustical and optical items without differentiating between the two groups, since 80% of the participants were verbalizers compared to 20% visualizers. However, descriptively, a comparison will be made here for the sake of a complete picture of results.

As *Table 1* shows, the subjects had more trouble recalling optical compared to acoustical items in general. Even though the mean performance was almost alike in the single condition, the visual dual-task seemed to be much more difficult than the verbal one. A comparison between the mean performance in the different conditions for the two groups individually will be made in the following section. The observed decrease in mean performance from the single to the dual condition was also stronger in the visual condition compared to the verbal condition.

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Insert Table 1 about here

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### 3.3.2 Verbalizers vs. visualizers

In the single condition, no significant mean differences were found between the two groups, neither in acoustical ($t$(113) = .80, n.s.; $r_{PB}$ = .07) nor in the optical presentation condition ($t$(113) = .93, n.s.; $r_{PB}$ = .09). The same results were obtained regarding the performance decrease between the single and the dual condition: No significant difference was found between visualizers and verbalizers in the acoustical ($t$(113) = .80, n.s.; $r_{PB}$ = .07) or the optical presentation condition ($t$(113) = 1.20, n.s.;

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Insert Table 2 about here

$r_{PB}$ = .11). To complete the picture, visualizers and verbalizers did not differ from each other concerning their mean overall score ($t(113) = .48$, n.s. ; $r_{PB}$ = .15).

In the dual condition, however, even though no effect was found for only acoustically presented digit series ($t(113) = .00$, n.s., one-tailed; $r_{PB}$ = .00), visualizers performed significantly better in the optical dual condition than verbalizers ($t(113) = 2.47$, $p < .01$, one-tailed; $r_{PB}$ = .23).

**3.3 Working memory**

Verbalizers and visualizers showed no significant differences regarding the *Simultaneous Storage and Processing* task ($t(113) = .01$, n.s.; $r_{PB}$ = .02). As shown in *Table 2*, the DSB correlated weakly with complex span task in all conditions.

## 4. Discussion

### 4.1 Cognitive strategies

The present study was conducted to investigate the role of cognitive strategies in the DSB task. It was found that visualizers perform significantly better with optical stimuli in the dual condition than verbalizers, while no effect of cognitive strategy was observed for acoustical stimuli. The choice of strategy was unrelated to working memory performance. Also, performance in all DSB conditions correlated weakly with performance in the experimental working memory task.

The rather weak correlations of the *Simultaneous Storage and Processing* task and the DSB raise some questions about the degree to which the DSB measures the same working memory facets as complex span tasks, which are widely applied in experimental situations. Even though complex span tasks have been described as consistent with a dual task situation (Oberauer et al., 2003), it has to be noted that a dual task comprising storage and processing differs from the dual task condition in the present study, in which two different spans have to be remembered. Thus, the finding highlights how different measures of working memory are prone to tap different aspects of the construct – as has already been shown for the *n-back* task and complex span tasks (e.g., Jaeggi et al., 2010; Kane et al., 2007; Li et al., 2008).

The *Simultaneous Storage and Processing* task is based on a series of experiments and a carefully developed working memory model by Oberauer et al. (2003). Also, several authors (e.g., Baddeley, 1992; Kyllonen & Christal, 1990; Salthouse, 1991) proposed the simultaneous storage and processing of information as one of the fundamental functions of working memory; therefore, a strong or at least medium correlation between the DSB and the task could be expected. The observed weak correlations therefore cast doubt on the use of the DSB as a "working memory benchmark measure" (Bireta et al., 2010) in clinical contexts.

Obviously, a single complex span task does not provide sufficient information about the convergent validity of the DSB as a working memory test; however, the present results suggest that the DSB taps different aspects of working memory than complex span tasks, which are prominent in present experimental working memory research (see Redick et al., 2012).

**4.2 The DSB task**

Visualizers and verbalizers showed no difference in the mean performance in the single task condition. The finding holds for optically as well as acoustically presented stimuli and supports the assumption that the presentation mode is not the critical factor for the choice of processing modality, as had been assumed by several authors (e.g., Penney, 1989; Suchan et al., 2006). Considering that visualizers showed better mean performance with optically presented items in the dual task condition completes this picture: taken together, the results imply a translation from the input modality to the preferred processing modality when possible and a decrease in performance when the translation prevented. This finding helps to clarify contradictory results concerning the different processing modalities in working memory: Crottaz-Herbette et al. (2004) found fundamentally differing neural correlates for visual and verbal working memory, while Schumacher et al. (1996) reported an almost complete overlap of the two. Both studies were based on the assumption of the presentation-mode being critical for triggering the respective modality in working memory. Schumacher et al.'s finding that acoustical and optical presentation resulted in nearly identical neural correlates can be easily explained by internal recoding of the presented stimuli by some participants.

Verbalizers, on the other hand, showed no advantage over visualizers regarding acoustically presented items. The absence of a performance difference in the single task condition can be explained in the same way as for the optical single condition: Subjects seem to be able to recode the perceived stimuli into their preferred processing modality.

The reason for the absence of a mean performance difference between visualizers and verbalizers in the acoustical dual condition may seem puzzling at first, but could be explained by the characteristics of the phonological loop: according to Penney (1989), acoustic stimuli are automatically translated into a sensory based acoustical code (corresponding to the articulatory loop within Baddeley's phonological loop) and can be maintained without deliberate use of attention. It may thus not be strictly necessary to actively monitor the articulatory loop to keep track of the acoustically presented digits. Support for this notion is given by the finding that sensory information in the auditory stream persists for up to 60 seconds (Engle & Roberts, 1982), considering that the presentation time in the present study never exceeded seven seconds.

**4.3 Conclusion**

The present study shows that cognitive strategies play an important role in the DSB. Persons who use a visual cognitive strategy perform better than verbalizers with optically presented stimuli when recoding into verbal processing is prevented. Within the framework of Baddeley's (1992) model, both the visuospatial sketchpad and the phonological loop can be used to solve the DSB task. The findings indicate that not the presentation mode but the preferred cognitive strategy may the critical factor for the resulting internal processing and should be considered in future studies on working memory processing.

Also, it seems that *Simultaneous Storage and Processing* – proposed by Oberauer et al. (2003) as well as Baddely (1992) as a fundamental working memory component – is not strongly connected to the abilities needed to solve the DSB. Thus, further research is needed to clarify the relationship between complex span tasks and the DSB. The correlations between all DSB tasks and the complex span task *Simultaneous Storage and Processing* proved to be only weak, indicating that the two tasks represent only partially related aspects of working memory.

For the clinical application of the DSB, however, the present findings clearly show that cognitive strategies play a role in the DSB and poor performance may be attributable to deficits in the applied cognitive strategy rather than global working memory deficits. In addition, the poor correlations with the experimental working memory task indicate that the performance in the DSB should be interpreted carefully with respect to working memory capacity.

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Table 1: Mean performance verbalizers and visualizers

| Condition | Verbalizers $n$ = 92 | | | Visualizers $n$ = 23 | | |
|---|---|---|---|---|---|---|
| | M(sd) | Min | Max | M(sd) | Min | Max |
| Acoustical single task | 6.35(1.88) | 2 | 9 | 6.70(1.85) | 3 | 9 |
| optical single task | 6.32(1.82) | 2 | 9 | 6.70(1.49) | 4 | 9 |
| Acoustical dual task | 4.35(2.35) | 0 | 10 | 4.35(2.37) | 0 | 10 |
| Optical dual task | 3.18(2.45) | 0 | 12 | 4.70(3.24) | 0 | 12 |
| Total performance | 20.20(5.83) | 5 | 35 | 22.43(6.12) | 12 | 35 |
| Decrease acoustical condition | .42(.21) | -.13 | .87 | .45(.22) | .04 | .80 |
| Decrease optical condition | .49(.21) | -.15 | 1 | .43(.22) | -.02 | .82 |
| Working memory | 5.55(1.77) | 1 | 10 | 5.52(1.59) | 2 | 9 |

*Table 1*: $n$ = Sample size; M = Mean; sd = Standard deviation; Min = Minimum; Max = Maximum; Decrease = Decrease in performance between single and dual Task: Percentage correct in single task minus percentage correct in dual task.

Table 2: Correlations between the DSB and working memory

| | | Acoustical ST | Optical ST | Acoustical DT | Optical DT | Total score |
|---|---|---|---|---|---|---|
| Working memory | $\tau$ | .19 | .20 | .18 | .21 | .27 |
| | $p$ | < .01 | < .01 | < .01 | < .01 | < .01 |

*Table 2*: $\tau$ = Kendall‘s $\tau$; $p$ = Probability of committing a Type-I-Error (one-tailed), ST = Single task; DT = Dual task

Figure 1: Time course of the study

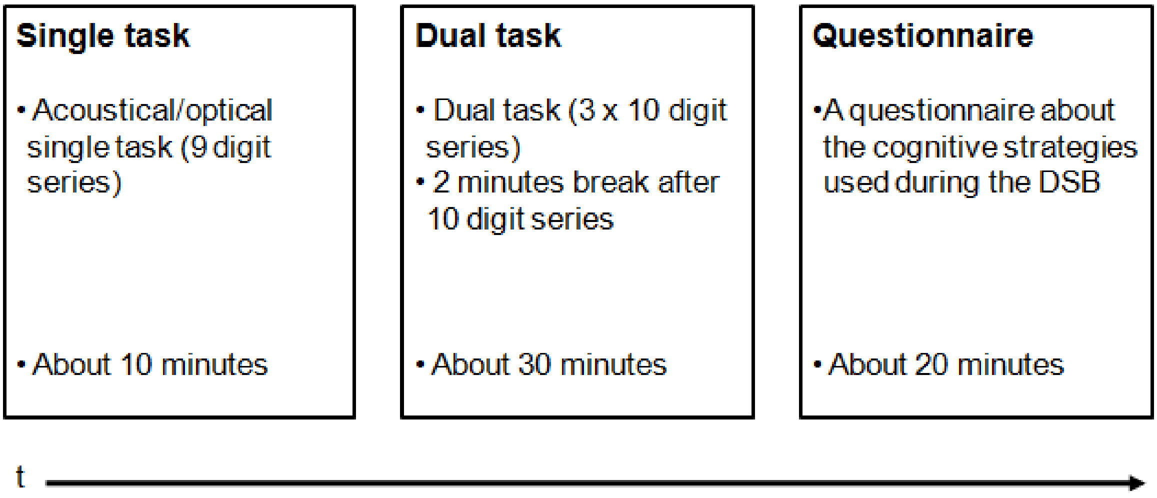


*Figure 1*: t = time passed during the session. The session lasted about 60 minutes