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Exploring serial positioning effects in Claeson-Dahl's Test for verbal learning and retention – a naturalistic study

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Psykologexamensuppsats. 2024

Abstract

Serial positioning effects and the derived recency ratio has shown increasing promise as clinical tools for evaluating neurocognitive disorders. These measures have remained unexplored in Claeson-Dahl's Test for verbal learning and retention (CDT). To correct this, the present study used naturalistic sample data ($N = 110$) from a project intended to update CDT's norms. I hypothesized the prevalence of three serial positioning curves: learning trial one (LT-1), retention and learning phase. Curves were constructed based on correctly recalled words for LT-1, retention, and learning phase proportional recall scores. Assessment of serial positioning patterns were made using visual inspection followed by statistical confirmation. Following this, regional variables of primacy, middle, and recency, were computed using the corrected regional scoring method on learning phase scores. These scores answered the research question, which was directed at exploring regional variables relationships with age, sex-related differences, and education. LT-1 and learning phase curves were confirmed to assume this pattern, while retention didn't. No significant differences between sexes on regional variables were found, joined by an absence of shared relationships between age and education. Exclusive relationships were however confirmed between regions, age, and education. The second research hypothesis assumed that recency ratio scores were positively predicted by age, independent of sex and education. No statistically significant differences between sexes were found, neither were there a statistically significant correlation with education. This, combined with age positively correlated with recency ratio scores, confirmed the second research hypothesis. Further research with these measures using CDT in clinical samples seems feasible.

Keywords: serial positioning effect, Claeson-Dahl's Test for verbal learning and retention, neuropsychology, memory, word list.

Sammanfattning

Seriepositionseffekter och recency-kvoten har visat potential som kliniska verktyg riktade mot neurokognitiva störningar, de har dock förblivit outforskade i Claeson-Dahls Test för inlärning och minne (CDT). Den aktuella studien syftade att fylla kunskapsluckan, vilket gjordes genom naturalistiskt insamlad data (*N* = 110) från ett projekt avsett att uppdatera CDT:s normer. Jag hypotiserade förekomsten av tre seriepositioneringskurvor: uppläsning ett (LT-1), retention och inlärningsfasen. Kurvor konstruerades med korrekt återgivna ord på LT-1 och retention, samt genom återgivningsskvoter för inlärningsfasen. Fastställandet av seriepositioneringsmönster genomfördes med visuell inspektion av kurvorna följt av statistisk bekräftelse. Genom den korrigerade regionala poängsättningsmetoden, tillämpad på inlärningsfasen, beräknades därefter regionsvariablerna primacy, middle och recency. Regionsvariablerna avsåg besvara forskningsfrågan, formulerad för att utforska regionala variablers relationer med ålder, könsskillnader och utbildningsnivå. Seriepositionsmönster bekräftades för LT-1 och inlärningsfasen, men inte för retention. Ingen signifikant skillnad mellan könen på någon av regionsvariablerna återfanns, likaså förelåg inget signifikant samband mellan ålder och utbildningsnivå. Ålder visade två signifikanta samband med svag effekt, positivt med recency och negativt med middle. Utbildningsnivå hade ett svagt negativt samband med primacy. Den andra forskningshypotesen förutsåg att recency-kvoten skulle positivt prediceras av ålder, oberoende av kön och utbildningsnivå. Inga statistiskt signifikanta skillnader mellan könen observerades på recency-kvoten och inget signifikant samband med utbildningsnivå återfanns. Ålder uppvisade däremot ett positivt samband med revency-kvoten, vilket bekräftade den andra forskningshypotesen. Framtida forskning med seriepositionseffekter och recency-kvoten i CDT kan genomföras med kliniska stickprov.

Nyckelord: Seriepositionseffekten, Claeson-Dahls Test för inlärning och minne, neuropsykologi, minne, ordlista

Tack

Först och främst tackar jag er som deltagit under datainsamlingen. Stort tack till mina handledare, Hanna Ljung och Susanna Vestberg, för ert engagemang och all hjälp. Jag vill slutligen tacka min familj, Jessica och Olivia, för ert stöd.

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Exploring serial positioning effects in Claeson-Dahl's Test for verbal learning and retention – a naturalistic study

Kolb et al. (2019, p.477) define *memory* as "... the ability to recall or recognize previous experience", which is an integral part of everyday living. Impairments in memory function directly affect quality of life, ranging between temporary effects, such as sleep deprivation, to the chronic disabilities caused by *neurocognitive disorders*. Consequences of a major neurocognitive disorder affect not only the individual but also their caregivers, adversely impacting their health, working capacity, and raising significant societal costs (Hopps et al. 2017; Reuben et al. 2022). This issue becomes more pronounced as Alzheimer's disease (AD), the most common major neurocognitive disorder, and other dementias are predicted to rise due to increased life expectancy (Nandi et al., 2022; 2023 Alzheimer's disease facts and figures).

Although memory disorders are commonly viewed as a process of gradual decline primarily concerning the elderly, patients with traumatic brain injury, epilepsy and major depressive disorder exemplify different symptomatologies affecting all ages (Helmstaedter et al., 2020; Wammes et al., 2017; Zaremba et al., 2019). Disorders also exhibit variational patterns in symptoms, dependent on affected brain regions, degree of severity and individual variation (Köhler et al., 2021). Furthermore, memories can be categorized into distinct types accompanied by independent neural networks; consequently, what might damage a certain memory system might leave another intact (Wammes et al., 2017). This complexity necessitates methods which support individualized diagnostical descriptions, backed by systematic research.

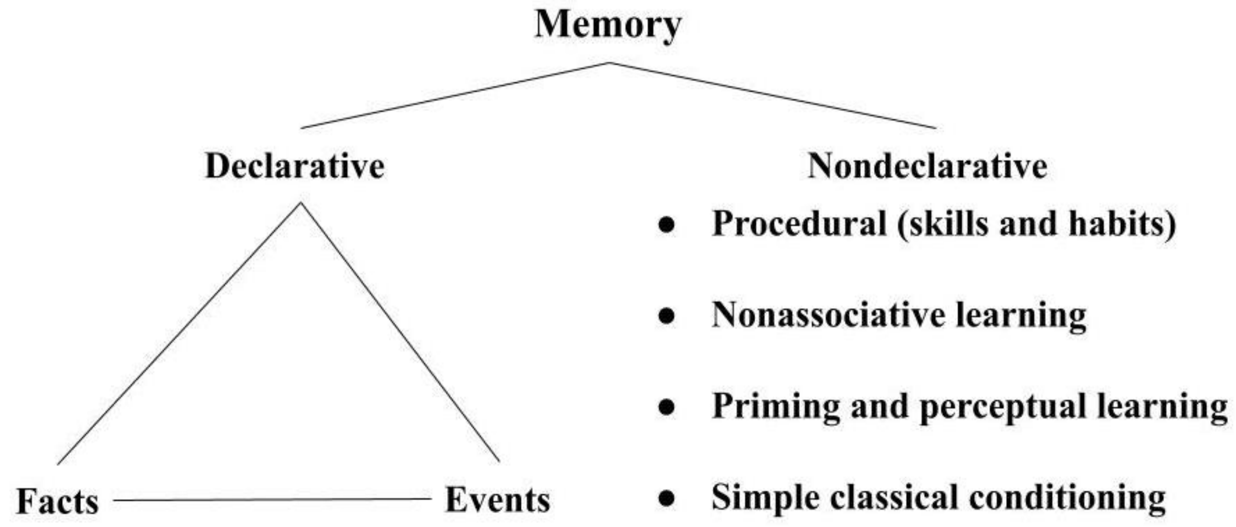
Neuropsychological tests have demonstrated their importance for functionally accurate memory-related assessments (Gordon et al., 2017). Supplementally to standard scores, process-related information such as systematic errors and learning patterns might be considered (Kaplan, 1988; Weitzner & Calamia, 2020). Research on an earlier recognized process-measure, namely the *serial position effect* (SPE), has demonstrated clinical promise (Bruno et al., 2021; Hill et al., 2020). This research might advance theories of memory, changing contemporary understanding of its core processes (Martín et al., 2013). Before exploring SPEs, understanding their background in memory research and how they are procured using neuropsychological methods is required. Thus, the subsequent section provides a basic review of memory systems and core processes, followed by a section defining *neuropsychology* and its methodological approach.

Long-term memory

As illustrated by Squire (2004), the leading contemporary view of *long-term memory* (LTM) includes explicit, or *declarative*, in addition to a *nondeclarative* implicit system. Figure 1 illustrates these and includes subcategories in an adapted version of Squire's model.

Figure 1.

Adapted version of Squire's model of memory



Declarative memory is generally considered as consciously accessible and separates into connected episodic and semantic parts, which respectively correspond to internal representations of experienced *events* and knowledge of *facts* (Squire, 2004). Episodic representations can be further fragmentized into subtypes (e.g., visual, auditory, or olfactory), served by different but interconnected neural structures (Siegel et al., 2016). Nondeclarative memories encompass *procedural memories*, *priming*, *perceptual learning*, *simple classical conditioning*, and *nonassociative learning*. Declarative knowledge of certain implicit memories undoubtedly allows for recall, such as willfully demonstrating a dance, which might imply conscious awareness. Schacter (1983) however, famously demonstrated a double dissociation between implicit and explicit memory systems, describing how a person with amnesia could play golf through external cues. The separate systems-approach retains a dominating position in the field, although evidence of shared structural processing and interconnectedness calls for more research (Kim, 2019; Renoult et al., 2015; Sheikh et al., 2019). While LTM pertains to stored information, available for recall, other mechanisms underlie temporary processing. This brings us to the concepts of *short-term* (STM) and *working memory* (WM).

Short-term- and working memory

Underlying long-term storage, sensory, STM and WM allow for initial processing, holding and manipulation of information (Ricker & Hardman, 2017). While *sensory memory* briefly represents the external world through perceived stimuli, STM requires higher order processes, implicating conscious awareness of held information (Doherty et al., 2019). STM plays a crucial role in WM, a concept pioneered by Miller et al. (1960), representing the ability to perform cognitive tasks. Unlike categories of long-term storage, both STM and WM are more attentionally contingent, as Oberauer (2019, p14) concluded: "By virtue of holding a selected subset of all available representations in memory, WM is by definition a form of attention.". Thus, core processes and neural networks in STM and LTM differ fundamentally. Several models have been proposed to define and explain WM, some more popular than others.

The multi-component model of working memory

The *multi-component model of working memory* (MCM), proposed by Baddeley and Hitch (1974), is historically and contemporarily one of the most prominent views of WM. Initially consisting of a *phonological loop*, *visuospatial sketchpad*, and *central executive*, later modified by Baddeley (2000) by integrating an *episodic buffer*. This addition was made after evidence of cross-system disturbance on recall, interpreted as caused by the disturbance of an underlying integrative process. It was also necessary to answer questions of consciousness and *binding*, how different stimuli and perceptual qualities are bound together into coherency.

Binding is performed by drawing on information held by the phonological loop and visuospatial sketchpad, which respectively contains verbal and visual information. As such, the episodic buffer explains how information held in WM can be integrated and further combined with LTM, creating a conscious and logical representation of reality. Goal oriented function is served by the central executive, responsible for tasks such as inhibition and planning (Baddeley, 1996). Evidence supporting the MCM has accumulated over time, showing for example that additional information might be processed if presented differently, such as adding visuospatial content if the phonological loop's limit has been reached (Logie et al., 2016).

However, the MCM has also met critique, perhaps increasingly in recent years. For example, as proposed by Logie (2016), the central executive might not represent an exclusive function. Executive functionality could instead be conceptualized as independent of the MCM, more accurately explained by interconnected functions, subsumed under one executive *neurocognitive domain*. Viewing WM as dependent on separate storage-sites has also been questioned, *state-based theories* instead suggest attention acting as a shared resource, partially used to maintain information in an activated state (D'Esposito & Postle, 2015).

Unitary WM-based models

Two competing state-based perspectives on WM are offered by the *Time-Based Resource Sharing-model* (TBRS) (Barroillet & Camos, 2015) and *Embedded Processes-model* (EP) (Cowan 1999). TBRS proposes attention as utilized during both storage and processing in WM, implicating reduced general WM-performance during high attentional load. This hypothesis is evidenced by how adding memory items reduces processing speed (Vergauwe et al., 2014). The phonological loop has however been accepted as domain specific in TBRS, contrary to the visuospatial sketchpad, which evidence suggests dependent on attentional resources.

The EP-model proposed by Cowan in 1999 further deconstructs WM, revisioning the concept as composed of embedded processes between LTM and attention. Briefly summarized, WM exists through attention directed at activated features of LTM, which happens through internal or external cues (Cowan, 2008). Recent studies have compared these theories experimentally, with results both supporting views of shared resources and specific memory modules (Rhodes & Cowan, 2018). Assumptions underlying these WM-theories were evaluated in a series of experiments by Doherty et al. (2019), which concluded that integrative efforts might be warranted since all models seemingly contained unique predictive value. Disregarding their perspectives on working memory definitions and function, all theories necessitate core memory processes, reviewed in the ensuing section.

Core memory processes

From declarative to nondeclarative, memories share the processes of *encoding*, *storage*, and *retrieval* (Alberini, 2011). During the encoding phase, interconnected networks interpret and transform information, preparing it for storage (Matthews, 2015). In a simplified manner, this happens firstly by *perception* determining external information available for encoding, further limited through *bottom up*- or *top-down* attentional processes (Melloni et al., 2012; Ueno et al. 2011). Bottom-up pertaining to differences in stimulus qualities affecting salience, while top-down is steered by motivational processes. Next, WM allows selective processing of information, which besides memory of events also implicate *intentional learning*, occurring alongside unintentional or *incidental learning* (Rodgers & Webb, 2019). Learning processes are sometimes semantically separated from encoding event-related memory, the former connected to practicing skills or memorizing facts (Kolb et al., 2019). Regardless of intentionality or definition of process, successfully encoded memories are considered as stored – *consolidating* over time through strengthened neural connectivity, providing resistance to alteration (Kitamura et al., 2017).

The physical storage site for a memory, or *engram*, likely involves brain regions responsible for its encoding, suggested by neural patterns during retrieval (Roy et al., 2022). Reactivating neural patterns for retrieval happens through associative functions, supported by external cues (Korkki et al., 2020). Successful cue-initiated retrieval depends upon similarities between cue and memory (e.g., matching color or context). Contrary to association, memories also possess comparative functionality, demonstrated through discrimination of previously encountered objects through *recognition* (Trelle et al., 2017). The relatively easier task of recognition compared to recall adds another metric, nuancing memory assessments by providing a lower threshold for participants. These processes can be researched using behavioral measures, commonly subsumed under the umbrella of neuropsychology (Harvey, 2012), explored in the subsequent section.

Neuropsychology and memory assessment

According to the American Psychological Association's online dictionary (2023), neuropsychology is: "the branch of science that studies the physiological processes of the nervous system and relates them to behavior and cognition…". Making this connection between brain and behavior while researching memory requires a combination of methods. Physiological measures used to examine memory, such as neuroimaging or biomarker analysis, provide specific results obtained with a relatively lower requirement of interaction and interpretation. This implies a comparatively safer and more reliable assessment, since interaction entails risk of misunderstanding – patients first need to convey their experience, which is then interpreted (Griffiths et al., 2020). However, physiological measures can't predict individual memory function or experience, which behavioral measures can (Weinstein et al., 2022).

In addition to the assessment of function, qualitative information obtained through interviews and questionnaires carries unique importance, supplementing the diagnostic description (Livingston et al., 2020). While formulating personalized care plans this knowledge is paramount, as simply curing a disease or reducing symptoms may leave the patient's goals or perspective on quality of life unaddressed (Kudlicka et al., 2023). Neuropsychological testing combines these perspectives through its collaborative effort between tester and participant, aspiring to obtain reliable and valid measures of psychological functioning. (Casaletto & Heaton, 2017). Indeed, neuropsychological testing proves accurate and uniquely contributive while researching or assessing several memory-related disorders, sometimes considered gold standard (Belleville et al., 2017; Wammes et al., 2017; Weinstein et al., 2022; Zaremba et al., 2019).

Contaminants and facilitations

Although psychometrically evaluated neuropsychological tests are reliable when utilized correctly, validity could still be questioned. The somewhat misleading term "*contamination*" has been used to describe how other psychological functions, not primarily intended for measurement, are implicated (Scharfen et al., 2018). Utilizing the term generally might be negatively misleading, as performing tasks and behaviors usually require several cognitive functions. These *contaminations*, or *facilitations*, might be important during neuropsychological evaluations, allowing interpretation of patterns between different tests. More fittingly, contamination happens when unwanted factors influence or constitute a measurement. Avoiding these factors require different forms of precautions, some more straightforward than others.

During a testing procedure, environmental contaminants such as unintended noise pose a more direct problem, contrary to facilitations from other psychological functions. They are however problematic when this facilitation unintentionally affects assessments. Pertaining to the domain of memory, measures from *verbal list learning tasks* (VLLTS) may exhibit significant variation when analyzed and compared (Ljung et al., 2018). These differences, when known, allow for an informed choice, motivating further research to assist clinicians in understanding and selecting their tools. Furthermore, processes observed from the participant during testing, such as systematic errors or SPEs, can provide information more relevant to the purpose than the total score (Bruno et al., 2016). Following this section on neuropsychology, in conjunction with the earlier review on memory, the next section starts with a brief history of SPEs.

The serial positioning curve

Brief history and definition

Although SPEs were first described by Francis Nipher in 1878 (Troyer, 2011), Ebbinghaus (1913) formulated the serial positioning term and propagated memory research. He noted that scores of word lists were unevenly distributed – presenting increased recall rates for initial and final items, separating the curve into *regions*. This observation was generalized to other sequentially represented stimuli, where *primacy* and *recency* effects respectively correspond to the initial and ending enhancement during recall (Atkinson & Shiffrin, 1968). Recent studies have also increasingly considered the *middle* region, defining it independently rather than as relative to primacy and recency regions (Consonni et al., 2017).

Mechanisms underlying these effects were proposed by Murdock in 1962, ideas which generally hold today. Murdock reasoned that the primacy effect derives from an advantage of initial rehearsal and processing of serial items, representing successful LTM-encoding (Atkinson & Shiffrin, 1968; Griffin et al., 2017). The recency effect is instead explained by STM-assistance allowed by imminent reproduction of presented items. Compared to LTM-mechanisms of primacy, evidence has initiated questioning of the STM-explanation for recency. For instance, recency has been confirmed long after STM-limitations (Mack et al., 2017). Others have argued that SPEs are highly dependent on task-demands (Morrison et al., 2014). Clinical evidence has generally supported the initially proposed mechanisms, as shown in the next section.

Clinical relevance of SPEs

When assessing LTM-impairment, especially pertaining to AD, scores from VLLTs have indeed been proven valuable (Belleville et al., 2017). These scores are commonly obtained from *learning* or *retention* (also known as delayed recall) *phases*, respectively representing immediate *free recall*-performance (defined as words repeated in any order), during learning trials or free recall after an extended delay. According to several manualized procedures, this delay usually varies between 20–25 minutes (Benedict et al., 1998; Delis et al., 2000; Lezak et al., 2012). Retention scores theoretically represents LTM better than scores from immediate recall, as they would arguably be less constituted by WM (Weissberger et al., 2017). This has been indicated by research on mild cognitive impairment (MCI), a potentially intermediary condition before dementia, marked by relative cognitive decline (Gainotti et al., 2014; Weissberger et al., 2017). The research showed that retention scores more reliably discriminated MCI-affected from healthy individuals than immediate recall. Retention also had a relatively increased accuracy in predicting conversion from a healthy state to MCI.

However, although retention implicates retrieval from LTM, successful encoding to LTM partially depends on WM-processes reviewed earlier. Thus, WM-functions affect what is subsequently encoded into LTM, possibly reflecting retention performance (Griffin et al., 2017). Since primacy scores doesn't share the same demands on embedded processes of WM, it may prove a relatively closer assessment of LTM-function than retention scores.

The clinical use of primacy as an independent score has been demonstrated by Talamonti et al. (2020), where conversion to early MCI was best predicted by reduced primacy scores during retention. This occurrence has been paired with a relatively conserved recency effect (Egli et al., 2014), respectively supporting LTM and STM associations with primacy and recency. Primacy have also shown promise in predicting gradual decline of everyday functioning, perhaps even more so than measures of demographic information and global cognitive functioning (Weitzner et al., 2022). Physiologically, a reduced primacy effect has been associated with prevalence of beta-amyloid plaques, a biomarker protein associated with AD, both in story recall and from a VLLT (Bruno et al., 2021; Tomadesso et al., 2019). Examining how scores are constituted through primacy and recency could also prove useful for differential diagnostics, as demonstrated by Kloth et al. (2020), where AD and behavioral frontotemporal dementia-patients' VLLT-scores were respectively driven by recency and primacy.

The recency ratio

Although seemingly paradoxical, recency scores have also been used to evaluate LTM-function, accomplished through the *recency ratio*. This measure is calculated by dividing correctly recalled words from the recency region at the first learning trial with their counterpart on retention (Bruno et al., 2016). Theoretically, this compares words from the recency region during the learning trial, primarily held in the STM, with words stored in LTM at retention. Higher recency ratios should therefore represent STM-dependency, precipitated by degraded LTM-function. This was demonstrated by Bruno et al. (2016), where recency ratio scores predicted cognitive decline on *Mini-Mental State Examination* (MMSE), which primacy and middle ratios didn't.

Disregarding the recency ratio, SPE-effects have been researched in conjunction with a multitude of VLLTs and with different definitional approaches, causing uncertainty about the generalizability of research results (Weitzner & Calamia, 2020). Next, I will review common

SPE-scoring methods, followed by widely used VLLTs with established SPE-finds, these will prove useful as comparisons to the examined VLLT in this paper.

Obtaining and defining SPEs in verbal list learning tasks

Three methods have primarily been used to describe SPE-scores, the standard, regional and *corrected regional approach*, all originating from the *California Verbal Learning Test* (CVLT). *Standard scoring* compares the individual's regional word recall sum with their total, creating a ratio (Delis et al., 2000). *Regional scoring* captures performance for each regional part, expressing successfully recalled words as a percentage of possible regional recalls (Foldi et al., 2003). These methods have strengths and weaknesses, for example, standard scoring considers the total score but disregards regional variations. Disproportionate regional sizes could also pose an issue by misrepresenting of regional quotas of the total score (e.g., when one region contains five words compared to the other two containing three). Regional scoring avoids this by examining regional quotas, which however doesn't consider the total score. This is illustrated when an individual's total score is expressed by a single region, which carries a different meaning compared to are naturally distribution (e.g., three words are successfully recalled, all in a primacy region comprising three words, creating 3/3=1 or 100%). Compared to standard scoring, the regional method has however shown an advantage in predicting conversion from MCI to AD scoring (Egli et al., 2014).

Campos-Magdaleno et al. (2016) discussed these issues associated with regional and standard scoring, developing corrected regional scores, calculated by weighting relatively larger regions and correcting the total score. According to their example, learning phase primacy, middle, and recency-recalls of 12, 9 and 11, with a total of 32 and a possible total of 20/40/20 for each respective region, would see redistribution to 27.5/27.5/27.5 and 12, 4.5 and 11 (after redistributing scores of the relatively larger middle region). Still, the scientific field of SPE-scoring remains pre-paradigmatic, containing a plethora of scoring methods, with research results based on different VLLTs, trials and phases.

The present study

No research has, to the author's knowledge, been conducted on SPEs or the recency ratio using Claeson Dahl's test for verbal learning and retention (CDT). Based on clinical evidence reviewed earlier, using SPE-measures with CDT could potentially improve its clinical value. Before conducting clinical practice and research with CDTs SPEs, an initial exploration is necessitated. An opportunity to realize this was offered when a project seeking to update CDTs normative data was initiated in 2013.

Following this, the present study aims to establish if there is a serial positioning curve in CDT during the first learning trial (LT-1), the learning phase or retention, which are commonly used in SPE-research (Weitzner & Calamia, 2020). The occurrence of SPEs is expected on CDT as they are considered pervasive in list-tasks (Oberauer et al., 2018). Age, education, and sex are to be explored as predictors of regional scores, should they be obtainable from a serial positioning curve on the learning phase. These variables have previously been noted to generally affect VLLT-scores (Espenes et al., 2023). Lastly, this study seeks to investigate the CDTs recency ratio's feasibility of predicting LTM-function. Although the sample consists of healthy individuals as compared to Bruno et al. (2016), LTM-decline has been associated with aging due to several reasons (e.g., Bettio et al., 2017; Chan et al., 2014). Thus, two research hypotheses and one research question was formulated.

Research hypotheses

1. A serial positioning curve can be established in a naturalistic sample on Claeson-Dahl's Test for verbal learning and retention for LT-1, learning phase and retention.
2. Age positively predicts recency ratio scores independent of sex or education, in a naturalistic sample on Claeson-Dahl's Test for verbal learning and retention.

Research question

- Does age, education, or sex by themselves or together, predict primacy, middle or recency-scores from the learning phase in a naturalistic sample on Claeson-Dahl's Test for verbal learning and retention?

Method

Participants

Participants were separated into two categories, male and female, based on their biological sex. Educational level was measured in years (EMY). The investigated sample consisted of 110 conveniently selected participants, 74 (67.3%) females and 36 (32.7%) males. Mean age was 38.01 years (*SD* = 16.47) ranging between 18 to 81. EMY had a mean of 14.82, ranging between 6 and 20 years (*SD* = 2.51).

Recruitment procedure and selection

Data used in this paper come from a project lead by Ia Rorsman and Hanna Ljung called "Normering av Claeson-Dahls test för inlärning och minne" conducted at the neurological department at Skanes university hospital stationed in Lund and Malmö. Recruitment and testing performed by licensed psychologists and psychologists in training, via the neurological department. Participants were recruited mainly by advertisements displayed in the departments' waiting rooms and in public places.

Sampling was conducted with the purpose of reflecting the Swedish population in terms of sex, education, and age. All collected sample data wasn't available for inclusion in this paper. Exclusion criteria were assessed individually but generally included disorders affecting cognitive function such as recent head trauma, neurological disorder, or severe mental disorder. Neuropsychological examination undertaken in the last decade was also a criterion for exclusion.

Claeson-Dahl's Test for verbal learning and retention

CDT was first published in 1971 (Claeson & Nyman, 1998), inspired by Luria's Higher cortical functions in man (1966). Four versions have been established to allow retesting without risking learning effects. Words included in CDT range between four to six letters and have been selected on the principles of a) high frequency of occurrence in the Swedish language b) two-syllable requirement c) exclusion of proper nouns and words of multiple classes d) limitation of ten words in the list and e) equivalence and association between the four test-versions. The test was also designed to avoid effects of education and verbal intelligence, evidenced by the decision to use high-frequency words. CDT can be considered inherently Swedish due to its development procedure, distinguishing it from translated alternatives.

All four versions of CDT include three adverbs, three verbs, two nouns, one adjective and one pronoun. CDTs validity in evaluating verbal memory has been confirmed in several clinical studies (e.g., Andersson-Roswall et al., 2012; Ljung et al., 2017). Test-retest reliability after six months measured in Pearson's correlation coefficient gave $r = .85$ for the learning phase, and $r = .41$ for retention (Bergman et al., 1988, as cited in Claeson & Nyman, 1998). Normative data comes from a sample of 400 individuals (200 males and females), stratified by age and randomly selected. Complementary norms are available from a limited sample of 93 individuals, collected between 1995 and 1997.

CDT-administration

CDT starts with a learning phase separated into trials. During learning, ten words are sequentially presented verbally by the administrator, these are repeated by the participant without demand for a particular order after a delay of fifteen seconds. The learning score formula is defined as the sum across all performed trials, starting from the first trial (t=1) up to the N^{th} trial. For each trial, the number of recalled words (W_t) is subtracted from ten, multiplied by the respective trial number (t). Mathematically, the learning score formula is represented as $\sum_{t=1}^{N}(W_t - 10) \times t$. Given the formula, higher scores therefore equal a worse performance. Learning ends when the participant either correctly recalls all ten words on two consecutive trials, or after a limit of ten trials.

Retention starts 30 min after the last learning trial. In this phase, the participant is asked to freely recall earlier presented words. Retention-score is shown in proportion, derived by comparing the sum of recalled words with the highest sum recalled in any single trial during the learning phase. Immediately after retention, recognition initiates, tasking the participant with recognizing all earlier presented words. This is performed by presenting three similar words, of which only one belongs original list. Recognition score is then given by the number of correctly identified words, also shown in percentage.

Research design

Since data was collected during a given time, this study can be considered cross-sectional. The nature of the research hypotheses and question, focused on relationships between variables, define this study as primarily correlational, further motivated with the absence of variable manipulation. How differences are examined between words, the study's explorative nature and the qualitative judgment involved, does however deviate from this definition.

Initial data analysis

Data was missing for two instances of age and one educational level-value. Missing values were analyzed with Little's missing completely at random (MCAR) test $\chi 2$ (2) = 3.12, p = .210, supporting that the missing values occurred without pattern. Imputation of the three missing values was performed with expectation maximization (EM) before further data analysis.

Normal distribution of age and EMY was primarily assessed by inspecting graphs and boxplots, values of skewness and kurtosis were also used, respectively not exceeding a conservative standard of ± 1 (Aron et al., 2013). Although Shapiro-Wilks test was significant for age (p = < .001) and EMY (p = .003), this could potentially be explained by the relatively high number of participants. Age and EMY was hence considered to be approximately normally distributed. Regarding statistical significance, a two-tailed threshold was set to $p = .05$. All data was analyzed using IBM SPSS statistics (Version 28). Due to their multiplicity and connection to the procedure, other variables are reviewed consecutively in the following sections.

Stepwise procedure for constructing SPE-curves and deriving variables

Defining serial positioning curves

The procedure used to graph curves from LT-1 and retention was identical, with words individually assigned a nominal variable using recall or omission as categories. To define a learning phase-curve a new procedure was developed. Proportions were calculated from correct recalls for each word divided by their possible total, defined by the number of conducted trials. This procedure was performed word-wise for each participant. Word scores were then divided by the number of participants, granting a sample-wide quote of recall for learning phase-words.

Examining serial positioning curves

To test hypothesis 1, the three completed curves were first visually inspected by the author before further statistical examination. This visual inspection was used to assess their congruence with a U-shaped pattern, a procedure used in earlier research (Bruno et al., 2021; Kloth et al., 2020). Two different statistical tests were used to further confirm a possible separation into the regional variables of primacy, middle and recency after the visual inspection. McNemar's test examined differences between threshold-words in LT-1 and retention, utilizing recall and omission as nominal variables, meeting its assumptions of dichotomous, mutually exclusive nominal variables taken from a random sample. In the same way, the Wilcoxon Signed-Rank Test was used to examine threshold words on the learning phase, its assumptions of symmetry and absence of outliers were met through assessment with boxplots.

Defining serial positioning regions

In constructing SPE-regions of primacy, middle and recency for LT-1 and retention, correct recalls were divided by number of words contained in the respective region, creating a regional score (e.g., if retention primacy contains four words, the formula for a participant could be 1+0+1+1/4). Regions from the learning phase were calculated according to the corrected regional approach (Campos-Magdaleno et al. (2016). For CDT this involved multiplying middle scores by 0.75, as visual inspection and statistical analysis determined that four words constituted the middle region, compared to three for primacy and recency. Next, all scores were summed to a corrected word total, serving as a denominator to create a proportion with regional scores in the numerator.

Statistical analysis of regional variables

Multiple regression-analyses were planned to explore if age, EMY, or sex, by themselves or together predicts regionals scores from the learning phase. Sex-related differences and relationships between variables were assessed before proceeding with multiple regression. T-test assumptions of normal distributions and equality of variances weren't met for primacy, middle and recency-scores. Although outliers in all three variables were identified by inspecting boxplots and descriptive data, defined as values exceeding ± 3 SD, their exclusion didn't affect t-test assumptions. These outliers were seemingly not caused by errors during measurement or data importation. Data transformation to reduce outlier-impact was unsuccessful, Mann-Whitney's U-test was thus applied as a replacement for independent t-tests, performed solely with outliers included.

Distributional shapes of primacy, middle and recency scores were explored graphically and through descriptive information of skewness, kurtosis, and variance. After this inspection, distributions were defined as asymmetric, mean-ranks are therefore compared on Mann-Whitney's U-test. Correlations were explored with and without outliers, using scatter plots and Pearson's correlation. Including outliers violated Pearson's correlations normality assumption due to excess skewness and kurtosis-values. Correlational effect size evaluations were assessed accordingly: low = 0.10–0.29, medium = 0.30–0.49 and strong = 0.50–1 (Pallant, 2020)

Defining and analyzing the recency ratio

The recency ratio was constructed by proportional recency-recall from LT-1, calculated with correct word-recalls divided by possible recalls, divided with corresponding variables on retention. In accordance with Bruno et al., (2016), a correction in the numerator and denominator (+0.1) were implemented to avoid data loss should the denominator be 0. Recency scores were log-transformed using the natural log, due to their positive skewness, and were thereafter considered to be approximately normally distributed. Following hypothesis 2, differences between the sexes and relationships between age and EMY were explored before performing a multiple regression analysis. Assumptions were met for an independent t-test on homogeneity of variance using Levene's test, although normality was questioned with Shapiro-Wilks being significant for both men (*p* = .010 and women (*p* = < .001). There was however a graphically evident normal distribution, in addition to skewness and kurtosis-values not exceeding ± 1. Considering that t-tests generally are considered robust (Rasch et al., 2007), it was carried out regardless. Regarding effect size values for the t-test, values around 0.20, 0.50 and 0.80 or above for Cohen's *d* were respectively considered small, medium, and large (Cohen, 1988). As a precaution, the t-test was complemented with a Mann-Whitney, where the distribution shapes were considered symmetric after visually inspecting boxplots.

Ethical consideration

The main project was granted ethical approval by the Swedish Ethical Review Authority. The same authority assigned it with registration number 2017/821. This was required since the project involved sensitive personal data, necessitating ethical approval according to Swedish law (SFS, 2003:460, 3 §). Based on this study's purpose and methods, which aligned with improving CDT in addition to a minimal risk of harming participants, project leaders deemed it to be encompassed by the ethical approval. Pseudonymization had been conducted in the original study, the data being stored separately from the identification key. The author of this study had no access to the identification key or when an individual's testing was conducted.

Results

Graphing and defining serial positioning curves

Bar graphs were constructed for LT-1(Figure 2.1) and retention (Figure 2.2) based on participants correct recall counts. Proportional learning phase scores are presented in Figure 2.3.

Figure 2.1

Number of correct recalls for all participants (N = 110) on the first learning trial in CDT

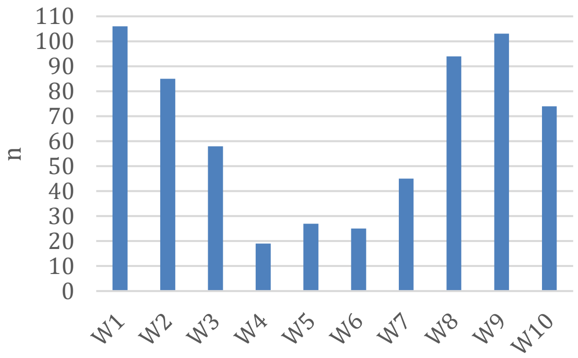
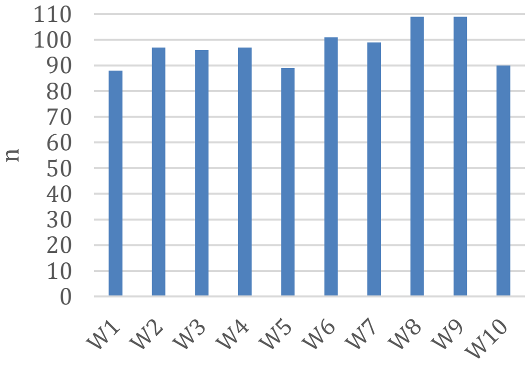


Figure 2.2

Number of correct recalls for all participants (N = 110) on retention in CDT



Note. CDT = Claeson Dahl's Test for verbal learning and retention; W = word, followed by a number signifying its position in CDT. The y-axis represents raw scores of all successful recalls.

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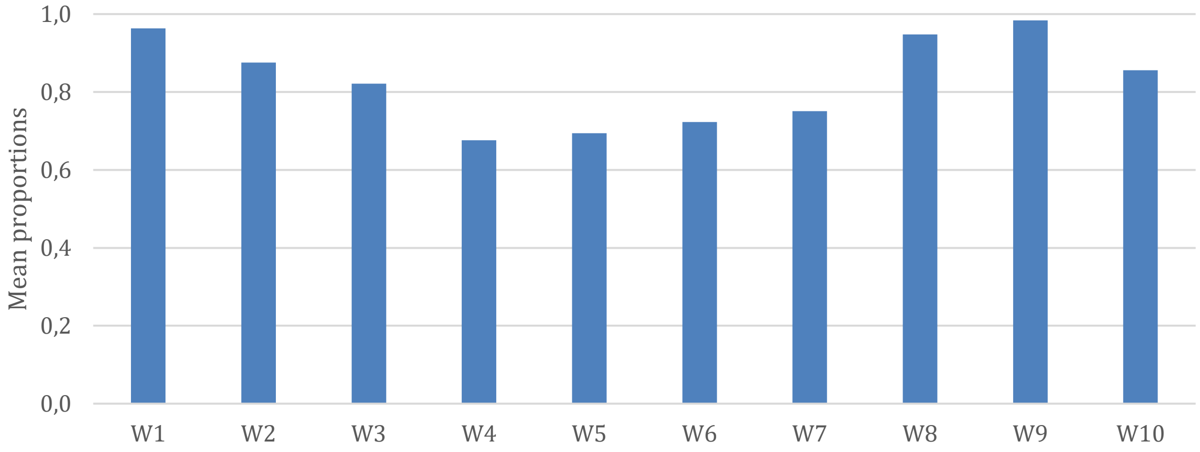
Figure 2.3

Proportions of correct recalls for all participants (N = 110) on the learning phase in CDT



Note. CDT = Claeson Dahl's Test for verbal learning and retention. The y-axis represents mean proportional raw scores for each word. This was derived by taking the mean of all participants' recall proportions, given by dividing their successful recall count with a possible total.

As shown in figure 2.1 and 2.3, serial positioning-patterns were observable in LT-1 and the learning phase, which wasn't the case for retention shown in figure 2.2. For LT-1 and the learning phase, their first three words, middle four words and last three words were respectively assessed to represent primacy, middle and recency regions. Statistically significant proportional differences on LT-1 with McNemar's test were confirmed (*N* = 110), with $\chi 2$ (1) = 24.48, *p* = < .001 between W3 and W4, and $\chi 2$ (1) = 39.05, *p* = < .001 for W7 and W8. Wilcoxon Signed-Rank Test confirmed statistically significant differences between learning phase threshold words (*N* = 110), W4 (*Mdn* = .71 [IQR = .25]) and W3 (*Mdn* = .83 [IQR = .30]) *Z* = -4.86, *p* = < .001 and W8 (*Mdn* = 1.00 [IQR = .10]) and W7 (*Mdn* = .80 [IQR = .40]), *Z* = 6.66, *p* = < .001. Thus, research hypothesis 1, which predicted that serial positioning curves could be constructed, was confirmed for LT-1 and the learning phase, not retention.

Constructing and analyzing regional variables

Four variables were made after completing the curves. These were the recency ratio and primacy, middle and recency-regions, derived from learning phase scores. Two outliers were identified in primacy and middle-regions and one in recency, which was shared with the primacy region. Including the outliers violated the normality assumptions of Pearson's correlation due to excessive values of skewness, analyses were therefore performed with and without outliers. An absence of shared relationships between age, EMY and the regional variables was identified.

Significant negative correlations with a weak effect size were found between EMY and primacy with $r = -.254$, $p = < .01$, and without outliers $r = -.293$, $p = < .01$. Age was significantly negatively correlated with middle region scores, including $r = -.334$, $p = < .001$ and excluding outliers $r = -.230$, $p = < .05$, respectively showing a medium and weak effect size. Recency was significantly positively correlated with age, showing weak effect sizes with outliers included $r = .251$, $p = < .01$, and excluded $r = .267$, $p = < .01$. The recency ratio was significantly positively correlated with age $r = .358$, $p = < .001$, marked by a medium effect size. Descriptives with outliers excluded or included, in addition to Pearson correlational values between age and EMY, are presented in table 1.

Table 1

Correlation coefficients and descriptive statistics on primacy, middle, recency, and recency ratio scores from the learning phase

Variable	Age	EMY	*M*	*SD*	Range	*N*
Primacy	.092	-.254**	.350	.029	23–42	110
Middle	-.334***	.085	.281	.034	13–36	110
Recency	.251**	.128	.369	.035	29–52	110
RecencyRatio	.358***	.123	1.000	.192	0.67–1.67	110

Note. EMY = Education Measured in Years. Recency ratio descriptives are shown before log-transformation.

* $p = < .05$.

** $p = < .01$.

*** $p = < .001$.

Exploring sex differences

Mann-Whitney's U-tests with outliers included were performed to explore sex-related differences between scores of primacy, middle and recency. For regional variables, the assumption of similar shape between distributional patterns were violated, mean ranks are therefore reported. The log-transformed recency ratio was examined with Mann-Whitney's U-test and an independent t-test for differences between males and females. No significant differences were found between sexes on mean ranks for regional variables, median or mean for the recency ratio. Results are shown in table 2.

Table 2

Descriptives for regional variables by sex, independent t-test, and Mann-Whitney U-tests

	M (*SD*)		MR/*Mdn*				
Variable	Males	Females	Males	Females	*p*	*U*(*z*)	*t*(Cohen's *d*)
Primacy	.36(.03)	.35(.03)	60.56	53.04	.246	1514.00(1.16)	-
Middle	.28(.04)	.28(.03)	54.36	56.05	.794	1291.00(-.26)	-
Recency	.36(.03)	.37(.04)	51.71	57.34	.385	1195.50(-.87)	-
RecencyRatio	1.01(.23)	1(.18)	.000	.000	.962/.180	1339.00(.05)	.20(.04)

Note. MR = mean ranks. Due to different distributional shapes for males and females, MR is reported for regional variables. Male and female distributions were deemed similar for the recency ratio, median is thus reported. Note that the distribution contained positive and negative values on respective tails after logarithmic transformation, creating a near null-situated median. *U* and *t*-values are shown for the recency ratio, with the *p*-value for the t-test in a parenthesis.

With this absence of shared relationships between age and EMY on regional variables, combined with the lack of sex differences, no further exploration using multiple regression analysis was merited. Thus, the research question was answered. Regarding the recency ratio, age was the only variable with a statistical relationship, confirming research hypothesis 2.

Discussion

The present study had several purposes and hypotheses. First, it aimed to establish serial positioning curves for LT-1, learning phase and retention in CDT. This aim was complemented with a research hypothesis predicting a successful outcome. Next, an aim was followed with a similar research question, where age, sex, and EMY-relationships with learning phase-based regional variables of primacy, middle, and recency-scores were to be explored. Finally, the recency ratio was to be investigated with age, sex and EMY, paired with a research hypothesis of age being the sole predictor of recency ratio scores. Important to note during this discussion is that results are obtained from correlational values, which might need confirmation with experimental research methods.

Could serial positioning curves be established?

Contrary to the first research hypothesis, a serial positioning pattern couldn't be determined for retention. This might be explained due to several reasons, jointly or individually. Although not confirmed statistically, W8 and W9 unexpectedly demonstrated enhanced recall compared to W10 on all graphs. This find seemingly goes against underlying theories of STM and SPEs, which would normally assume a higher last item recall-rate compared to other recency items (Oberauer et al., 2018).

Perhaps their word class influences recall rates as both W8 and W9 are paired nouns, possibly creating a semantic clustering effect (Campos-Magdaleno et al., 2016). Additionally, nouns could support memory strategies easier than adverbs or adjectives alone. This was exemplified in the CDT-manual by Claeson and Nyman (1998), who noted that W8 and W9 were commonly used in stories, which could also enhance recall of other words. Using nouns as anchor points for visual memory strategies (e.g., method of loci) would also implicate facilitation according to MCM, where WM could utilize the visuospatial sketchpads capacity (Pearson & Keogh, 2019). TBRS and EP would instead assume no enhanced effect with the visuospatial sketchpad. Emotional salience could also play a role, as one of the words commonly represents a significant caregiver.

These effects which plausibly enhances recall for W8 and W9, could affect concurrent recalls through the first-recall probability effect. This would prompt participants to initiate recall on a point far from primacy words, enhancing recall rate for proximally situated words but reducing the primacy effect (Oberauer et al., 2018). Also interesting is that W1-recall rate during retention seems relatively lower than W2 and W3, which wasn't observed on LT-1 or learning phase-scores. Perhaps due to word class, first-recall probability effect or strategies.

Although CDT uses a comparatively longer interim period between learning and delayed recall, ceiling effects can be inferred in delayed recall from its normative data (Claeson &

Nyman, 1998) which was also observed in this study. These could be caused by the relatively sparse number of words and potentially high trial number as compared to other VLLTs. For a clinical sample with LTM-memory deficits, however, ceiling effects would not be expected.

Age, education, and regional variables

Disregarding the middle regions with outliers, all correlational effect sizes with age were weak. This was expected in a healthy sample of varied ages, where gradual cognitive decline is attenuated due to the age spread. Analyses using a sufficient sample with groups, including individuals exceeding 81 years of age, should theoretically yield larger and more reliable effect sizes. Indeed, analyses were initially planned to be performed on age-groups, which could have further demonstrated effects of cognitive decline with age. However, due to a paucity of individuals belonging to age-groups 50–64 and 65–74, this plan was discontinued. Group based analysis was also planned with EMY, but a shortage of individuals with EMY lower than twelve years prevented this.

The effects of education on regional variables

EMY was significantly and negatively correlated with primacy scores, which wasn't the case for age. Before drawing conclusions about negative effects of EMY, the interconnectedness of regional scores warrants consideration. A higher EMY does indicate lower primacy scores, these scores are however a ratio, further constituted by middle and recency. One reason could be that higher educational level reduces the primacy effect with an increase of middle and recency-scores, partially explained through an executive advantage (Colangeli et al., 2016). Another reason unique to CDT and connected to this advantage, is that higher educational level could effectuate fewer conducted learning trials, which attenuates SPEs by flattening the recall-curve.

The effects of age on regional variables

In line with Griffin et al. (2017), increasing age was positively correlated with recency scores, the inverse relationship true for scores on the middle region. This result is somewhat expected considering earlier finds of increased STM-dependency and reduced executive function associated with aging (Ferguson et al., 2021). Griffin et al. (2017) conjectured increasing vulnerability to proactive and retroactive interference with higher ages. These interferences respectively originate from words of primacy and recency, impinging middle region-words from both directions. Unexpected however, was the absence of a negative correlation between age and primacy. This seems counter-intuitive as increasing age, which is associated with declining

LTM-function (Bettio et al., 2017; Chan et al., 2014), should negatively impact primacy scores. Instead, the relatively increased ratio of recency seemed driven by a decrease of middle scores.

The recency ratio

Only age showed a correlation with the recency ratio, significant at the level of $p = < .001$ and defined by a positive relationship of medium strength. Of all variables, the recency ratio showed the strongest relationship with age, surpassing the correlation and significance values for recency scores. This effect could perhaps be even larger considering the possibility of measurement errors. As reported earlier, 6-months test-retest reliability on retention scores in CDT was $r = 0.41$. This can be considered low compared to $r = 0.76$ on RAVLT by Stricker et al. (2021), obtained from a US-sample with mean follow-up time of 16.7 months.

Low reliability on retention could reduce the recency ratios correlational strength, as half of the ratio is computed by using these scores. Although test-retest reliability from CDTs learning phase is remarkably stronger ($r = .85$), data for CDTs first learning trial isn’t available, which renders its impact indiscernible. Should this information be available, disattenuation might be used to tentatively assess true correlational values (Wang, 2010). Procuring this information by retesting the project’s CDT-sample would therefore be important for the conclusions drawn in this paper. An interesting question relevant to the recency ratio and exclusive to CDT, is the possibility of disadvantaged rehearsal for participants with few learning trials. Two reasons for completing early might be due to superior memory function and memory strategy usage, alone or combined. These participants possibly show perfect recall on LT-1 but are disadvantaged on retention.

Strengths and weaknesses

Although age and EMY-variables could have included more individuals of higher age, and those with less than nine EMY, the number of participants included seems to have produced reliable results, with correlational significance values below $p = 0.05$. As mentioned above, the effect sizes might also be underestimated due to measurement errors. Another strength is the combined visual and statistical approach used to confirm SPEs. Understandably, it might be tempting to compute regional variables without this investigation. A reasoning possibly based on the pervasiveness of SPEs in sufficiently long list-tasks, as remarked by Oberauer et al. (2018) in their comprehensive summary and assessment on benchmarks for WM. However, adopting this reasoning and assuming SPEs on a list without further investigation pose several risks. As evidenced by CDTs retention-curve in this study, proceeding with regional computation before visual inspection risks missing violations of the expected pattern. Visual confirmation also needs further statistical analysis, refuting random pattern occurrence and justifying regional separation.

Although standard and regional scoring methods have been researched more thoroughly, the corrected regional method counteract several of their weaknesses. Basing scores on the completed learning phase also raises reliability due to using multiple measures. Predicting quotas obtained through standard or regional scoring with age and EMY could however have yielded other valid results, especially with the regional methods narrowed focus. Solely considering this to be a strength could therefore be disputable, motivating investigating with other scoring approaches on clinicals samples using CDT. Furthermore, although efforts were made during recruitment so that the sample would reflect the Swedish population, it can still be considered a convenience sample. The results therefore need to be interpreted with this in mind.

Like age, educational level was also planned to be separated into groups for further analysis. Due to few individuals belonging to a primary level of education, defined as less than nine years, this wasn’t feasible. Furthermore, the samples high educational level could challenge its external validity pertaining to the general population. This might however be partially counteracted by the design inherent to CDT, which aimed to reduce the effects of higher education. Another potential issue is present in participants exceeding the twelve years of secondary Swedish education. After primary and secondary school, benefit of additional years could increasingly vary in quality. This can be exemplified with two imaginary participants, where the first has obtained a high EMY by studying separate university courses, and the second has completing advanced studies, working as a professor. Proportions between males and females were also an issue, possibly misrepresenting males due to their smaller number. This also affected the statistical analyses trying to explore sex-differences on regional variables, requiring the utilization of mean-rank scores with a non-parametric Mann-Whitney’s U-test.

Several outliers were apparent in the sample, which was managed by performing separate analyses to investigate their impact. These are however included in the recency ratio analyses due to their lessened effect as compared to regional variables. There is a possibility that these outliers represent a different population (e.g., belonging to a clinical population), which would necessitate their removal from the sample. Selection bias could also affect the external validity in several ways. Perhaps those who agree to participate are relatively well-functioning compared to the general population, as indicated by the high EMY. Others could instead participate after noticing a decline in memory-function, which could incorporate subclinical individuals.

Another potential weakness, pertaining to the construct validity of the regional variables, comes from using learning phase scores. While including all trials does raise the reliability of regional variables, it simultaneously contaminates them. This is especially true for recency-words, as increasing numbers of trials implicate their transfer to LTM. Finally, inter-rater reliability could also be important for these results. As discussed earlier, the collaborative nature of neuropsychological testing could influence the outcome. However, due to CDT being strictly manualized, this risk could be considered low.

A discussion on VLLTs and their differences

To accentuate the need for standardization in the SPE-research field, three VLLTs frequented in SPE-research will be reviewed and compared to CDT: Rey- Auditory Verbal Learning Test (RAVLT), Hopkins Verbal Learning Test-Revisited (HVLT-R) and the California Verbal Learning Test-II (CVLT-II).

RAVLT

Trials are performed using fifteen nouns with word-lengths between three to eight letters, presented verbally with one-second intervals by the administrator and to be repeated immediately by the participant (Lezak et al., 2012). After five trials, an interference list composed of fifteen different nouns are presented, followed by a sixth trial with the original list. retention based on the original list initiates twenty minutes after completion of the sixth trial, followed by a recognition task.

HVLT-R

Twelve nouns are equally divided into three semantic categories, using word-lengths of three to eight letters (Benedict et al., 1998). These words are presented with two-second intervals, repeated by the participant during three learning trials. retention starts after 20–25 minutes, followed by a recognition task.

CVLT-II

Sixteen nouns are equally divided into four semantic categories, word-lengths are three to nine. Like RAVLT, this VLLT includes five learning trials and a similar interference list (Delis et al., 2000). After presentation of the interference list, the participant is asked to freely recall the first list, followed by a cued recall. Retention in free and cued forms are initiated after twenty minutes. CVLT-II ends with a yes/no recognition task and a subsequent forced choice recognition after ten minutes. Although there is a third edition of CVLT, published studies utilizing it are scarce due to its recency, the second edition is therefore referenced.

CDT compared with other VLLTs

Starting with word-characteristics, CDT is conspicuous in several ways. First, it utilizes the smallest word count, substantially lower than RAVLT's fifteen and CVLT-II's sixteen. Second, included words belong to a variation of different word classes, rather than solely using nouns as the others do, without considering potential clustering of semantic categories. Regarding trial-procedures, CDT is uniquely flexible in its number of learning trials, varying between two and ten determined by when or if the participant successfully recalls all words on two consecutive trials. CDT could therefore be performed with either the least or highest number of trials of the VLLTs reviewed.

The varying trial number in CDT could provide valuable information but might also complicate interpretation of test results. For example, fewer trials due to efficient memory strategies and attentional resources could theoretically be disadvantageous on retention, explained by fewer opportunities to rehearse (encode) words into LTM-storage (Murdock, 1962). When researching and standardizing process-measures such as SPEs, variations in performed trials could therefore theoretically affect construct validity.

Both RAVLT and CVLT-II include an interference list before their sixth learning trial, which could affect individuals scores on retention and recognition negatively (e.g., due to misattribution). Additionally, retention in CDT initiates 30 minutes after completing the learning phase, compared to the 20–25 minutes in other VLLTs. These are some of the notable differences between CDT and the other VLLTs, further comparisons could be made, for example between mean statistics of letters and syllables involved.

Future research

A potential point of criticism is that additional studies risk adding to the inflation of general serial positioning research. However, by not exploring how SPEs manifest in CDT and establishing interpretation guidelines for their usage, potential SPE-data will be lost, in addition to defaulted clinical benefits. Results obtained in this study can be used as a contrast to other VLLTs SPE-observations, as variations in administration and test construction influence how SPEs are expressed (Weitzner & Calamia, 2020).

More research with CDTs serial positioning effects on clinical samples is warranted, which could be conducted by using different scoring methods on LT-1 or the learning phase. Caution is however advised when constructing scores based on retention, as this curve didn’t assume a typical U-shape. Such disturbances generally seem true for several VLLTs, and standardization measures to avoid effects impacting SPEs could be considered. Future research could also explore cognitive functions behind varying trial numbers in CDT, which presents a potential process score. Another potential for future research lies in exploring effects of social class and ethnicity on CDT, as this has previously been reported to affect performance (Byrd & Rivera-Mindt, 2022). Finally, experimental studies could further explore differences between words in CDT connected to theories of working memory.

Conclusions

Serial positioning curves were observed on learning trial on and the learning phase, not retention. Age and education affected regional scores in several ways, perhaps most notably, increasing age was positively correlated with recency and negatively with middle. The recency ratio was exhibited the strongest correlation with increasing age out of all variables. Thus, serial positioning measures seem to hold potential in Claeson Dahl’s test for learning and retention.

Author contributions and responsibilities

I was responsible for processing and analyzing data, in addition to formulating the research question and hypotheses. Data collection was performed by the neurological department in Skanes university hospital, which I didn’t partake in.

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