NEURAL SIGNATURE ON EASY TO DIFFICULT LEVEL OF N-BACK WORKING MEMORY LOAD TASKS IN HEALTHY SUBJECTS – A STUDY OF COGNITIVE PROCESSING USING EEG

KARTINA ISMAIL

UNIVERSITI SAINS MALAYSIA

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KARTINA ISMAIL

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF ABBREVIATIONS

BOLD	Blood-oxygen-level-dependent
CE	Central Executive
Cr	Central
CLT	Cognitive load
EF	Executive Function
EEG	Electroencephalography
FFT	Fast Fourier Transform
Fr	Frontal
LTp	Left Temporal
LTS	Long Term Store
MEG	magnetoencephalography
ms	Millisecond
Pr	Parietal
ROI	Region of Interest
RTp	Right Temporal
Oc	Occipital
STM	Short-term memory
STS	Short-term store
SR	Sensory register
S-R	Stimulus-Response
WM	Working memory
WMC	Working memory capacity

TANDA NEURAL PADA TAHAP MUDAH KE TAHAP SUKAR TUGASAN MEMORI KERJA N-BACK BAGI SUBJEK SIHAT – KAJIAN PEMPROSESAN KOGNITIF MENGGUNAKAN EEG

ABSTRAK

PENGENALAN: Isu dalam proses kognitif dihubungkan dengan kekurangan memori kerja. Tujuan kajian ini adalah untuk menilai pemprosesan saraf semasa tugas beban memori n-back pada tahap mudah ke tahap sukar bagi subjek sihat daripada data EEG.

METODOLOGI: 28 peserta sihat (25 lelaki, 3 perempuan) yang mempunyai sekurang-kurangnya sembilan tahun pendidikan terlibat dalam eksperimen ini. Mereka diminta menyelesaikan empat tahap tugas beban memori kerja yang bertahap mudah (0-back ke 1-back), sederhana (2-back) dan sukar (3-back). Arahan telah diberikan sebelum tugas dimulakan. Reka bentuk kajian ini adalah keratan-rentas bersama kaedah pensampelan mudah. EEG dirakam menggunakan ANT Neuro 64-saluran. Data dikumpulkan dengan borang persetujuan peserta dan prapemprosesan menggunakan perisian Besa Research 6.1. Data yang diproses kemudian dianalisis dengan ujian ANOVA sehala dan Friedman di mana $p < 0.05$.

HASIL: Hasil daripada osilasi theta menunjukkan bahawa perbezaan secara statistik pada bahagian frontal [$F(3,108) = 10.91$, $p = 0.000$], central [$F(3,108) = 14.11$, $p = 0.000$], temporal kiri [$F(3,108) = 5.24$, $p = 0.002$], temporal kanan [$F(3,108) = 4.09$, $p = 0.009$], parietal [$F(3,108) = 3.83$, $p = 0.012$] dan oksipital [$F(3,108) = 4.40$, $p = 0.026$]. Selain itu, central theta menunjukkan statistik perbezaan yang signifikan pada semua keadaan tugas beban memori kerja n-back ($p < 0.05$). Hanya tugas beban memori kerja n-back tertentu yang menunjukkan perbezaan min secara statistik di bahagian lain. Osilasi gamma menunjukkan perbezaan secara statistik antara 0-back dan peningkatan tahap tugas beban memori kerja n-back, $\chi 2$ (23) 296.962, $p < 0.000$. Pembetulan Bonferroni menunjukkan perbezaan statistik gamma pada temporal kanan semasa 0-back dengan 1-back (*p*=0.016), 2-back (*p*=0.023) 3-back (*p*=0.030) dan temporal kiri pada 0-back dengan 3-back (*p*=0.009). Bahagian otak lain tidak menunjukkan penemuan yang signifikan untuk osilasi gamma selain daripada kedua-dua belah temporal kiri dan kanan. **KESIMPULAN:** Hasil EEG secara amnya menunjukkan bahawa peningkatan beban memori kerja mempengaruhi penurunan osilasi theta manakala osilasi gamma berlaku di dua bahagian tertentu dengan keadaan tugas beban memori kerja. Oleh itu, kajian ini telah menunjukkan peranan komponen memori kerja seperti perhatian, penghambatan dan penarikan semula terhadap orang dewasa yang sihat.

Kata kunci: memori kerja, n-back, EEG, theta, gamma

NEURAL SIGNATURE ON EASY TO DIFFICULT LEVEL OF N-BACK WORKING MEMORY LOAD TASKS IN HEALTHY SUBJECTS – A STUDY OF COGNITIVE PROCESSING USING EEG

ABSTRACT

INTRODUCTION: Issue in cognitive process is linked with deficit of working memory. The purpose of this study is to assess the neural processing during easy to difficult level of n-back working memory load task in healthy subjects from EEG data.

METHODOLOGY: 28 healthy subjects (25 male, 3 female) who have completed at least nine years of education were involved in the experiment. They were required to complete four level of working memory load task which level as easy (0-back to 1back), moderate (2-back) and difficult (3-back). Instructions were provided before each task start. Cross-sectional design with convenient sampling was applied in the study. EEG was recorded using ANT Neuro 64-channel. Data was collected with participant consent form and pre-processing was done in Besa Research 6.1 software. The processed data then analyse with one-way ANOVA and Friedman test where $p < 0.05$.

RESULTS: Theta oscillation shows it was statistically difference in frontal [F (3,108) = 10.91, $p = 0.000$], central [F (3,108) = 14.11, $p = 0.000$], left temporal [F (3,108) = 5.24, $p = 0.002$], right temporal [F (3,108) = 4.09, $p = 0.009$], parietal [F (3,108) = 3.83, $p = 0.012$] and occipital [F (3,108) = 4.40, $p = 0.026$]. Additionally, central theta indicated 0-back was statistically significant difference in all conditions of n-back working memory load task ($p < 0.05$). There was only certain n-back working memory load task show statistically mean difference in another region. Gamma shows statistically difference between 0-back and the increase level of n-back working memory load tasks, $\chi^2(23)$ 296.962, $p < 0.000$. Bonferroni correction revealed that gamma was statistically difference in the right temporal on 0-back with 1-back (p=0.016), 2-back ($p = 0.023$) 3-back (*p*=0.030) and left temporal on 0-back with 3-back (*p*=0.009). All other regions do not show any significant finding for gamma oscillations apart from the two regions of left and right temporal.

CONCLUSION: The EEG results generally indicated that increase of working memory load influences the decline of theta oscillatory whereas gamma oscillation occurs in two regions with specified working memory load task condition. Thus, the study presented the role of WM component such as attention, inhibition and recall in healthy adults.

Keywords: working memory, n-back, EEG, theta, gamma

CHAPTER 1

INTRODUCTION

1.1 Study Background

Working memory (WM) plays an important role in cognition and accountable for our information process. It is a type of short-lived memories which can be distinguished from mental processes. For example, remembering formulas to solve a mathematical problem or listening to the keynote before playing piano (Schwartz, 2016) defined WM as the neural systems and cognitive processes that are preserved the capacity to provide knowledge for brief periods of time in an active conscious state. As the name implies, the WM concept reflects what is more than just a memory, how it works and its multiple component systems or a collection of an interrelated process which contribute to our cognitive function (García-Madruga *et al*., 2016; Jacobs and Silvanto, 2015). The term was introduced in the 1960s when the era dominated by the psychological concept of stimulus and response (S-R) to emphasize what are the factors to achieve goals in humans and animals. Baddeley (2010) however stated the WM concept has long existed based on computer program development. Not just that, the evolution of primary and secondary memory research in the 1880s have influenced the division of memory type (Cowan, 2017). The difference between those is that the primary memory manifests a person into a non-familiar situation (like names, ideas, things, and places) that has never been thought in mind, while secondary memory projects short-term memory (STM) to a pattern of neural firing in certain situation. For instance, speaking in a foreign language and mistakenly change the speech to match the foreign speaker's accent. With that, the speaker was influenced by what was said to the point an unconscious (and therefore uncontrollable) aspect of our short-term memory (Cowan, 2017)

Broadbent meantime, added the importance of hearing with the concept of auditory perception, approach of attention as a filtering process, and suggested rehearsal as a measure of reactivating information in primary or STM (Baddeley, 2012). Atkinson and Shiffrin (1968) further presented the structure of the memory system model which features the sensory register (SR), short-term store (STS), and long-term store (LTS). According to the memory system, external input will first enter the sensory register (SR) through the visual system including several hundred-millisecond decays of an initially accurate visual image to identify this system as a unique component of memory. The decay period nonetheless is not clear during the condition. The next component assumed short-term store (STS) will decay and disappear completely, but it was suggested that the decay duration is longer than the sensory register (SR) due to requiring rate in the short-term store (SRS) is difficult to estimate by the subject-controlled processes. That means, the outcome from the subject depends on many factors such as the instructional set, the experimental task, and experience. Nonetheless, the long-term store (LTS) suggests transferring the information from SR or STS and expected to not decay. For example, subjects must repeat sequences of digits. If a particular sequence was presented every several tasks, it will be constantly learned. Consequently, the shifting to LTS has been placed.

Unlike animal, human have diverse abilities in many aspects of normal WM function include ability to manipulate active representations sustain and rehearse, along with a limit of 3-4 items or chunks of information (Carruthers, 2013). For instance, comparative study by Elmore and Wright (2015) shows that monkey visual short-term memory (VSTM) capacity is at most one item in contrast to three in human. This characterization provides insight on how VSTM declines with memory load would influence species similarities based on close functional relationships. Moreover, Ghirlanda *et al.* (2017, p.2) explained that "human achievements such as complex societies, art and science" are something that animal is lack in spite the struggle to determine human cognitive element. Chuang *et al*. (2019) indicated that neuroimaging studies on memory load and the higher order WM function, is less examined in human. Indeed, it is important to address WM due to it link to our intelligence and resist interference from unsafe or dangerous situation such as fight-and-flight or hazardous working environment. Not to mention, research by Martini *et al.* (2019) observed the differences among adults in one or more behaviors, traits in working memory capacity (WMC) and a central moderating factor of memory retention. Their findings proclaim that WMC is not only to synchronize sleep-related, as well with wakeful-resting which link to memory consolidation.

As evidence increased on the relation between WM impairment, researchers have collected possible cause and approach to improve WM and inhibitory control (Larsen *et al*., 2019). To illustrate, recent studies by Wangkawan *et al.* (2020) had utilized N-back, running memory tasks and Pirate Ship game to assess performance of in children. Additionally, Buschman *et al.* (2011, p.1) described cognitive load in the animal frontal cortex and "frontal eye fields (FEF) and the parietal cortex" during visual working memory (VWM) task. Note that frontal lobe is considered as emotional control hub and accommodating the personality and decision-making, it situated the memory and sensory system which allow someone to determine information that is placed elsewhere (Badre & Nee, 2018; Barrash *et al.*, 2018; Zaman, 2016). By the same token, multiple tests were listed as indicators of cognitive control tasks from working memory updating (or updating), complex-span tasks (or Cspan), instant memory for temporary bindings (or binding), secondary memory for associations (or SM), tasks measuring response inhibition (or inhibition), and tests of fluid intelligence (or Gf) (Wilhelm *et al.*, 2013).

Based on such test and data, studies have confirmed that individual differences in working memory capacity reflect the ability to build, maintain and update random bindings (Martini *et al., 2020;* Miller *et al.*, 2019; Slana Ozimič & Repovš, 2020).

Several neuroimaging studies have specifically investigated the brain areas involved in WM and cognitive load such as fMRI (Howard *et al.*, 2015; Sörqvist and Rönnberg, 2014), magnetoencephalography (MEG) (von Lautz *et al*., 2017; Yang, 2017), transcranial magnetic stimulation (TMS) (Bakulin *et al*., 2020), electrocorticography (ECoG) (Alagapan *et al*., 2019) and electroencephalography (EEG) (Dan and Reiner, 2017; Mohamed *et al*., 2018). The EEG, which a non-invasive tool, often prefer as it can obtain electrical activity and provide neural oscillation data with high temporal resolution (Noh, 2016). Apart from that, the neural data can be analysed with multivariate pattern analysis (MVPA) and accommodating neuroscience research (D'Esposito and Postle, 2015). The technique usually pair together with neural oscillation activity study which commonly associate with WM binding and the maintenance of information that focused on the oscillation "code" (Pina *et al.*, 2018) . Frequency bands in the EEG power spectrum are varies from delta (1 to 4 Hz), theta (4 to 8 Hz) (Tsipouras, 2019), alpha (8 to 12 Hz), beta (13 to 40 Hz) to gamma (>40 Hz) (von Lautz *et al.,* 2017). Past study uses EEG have also proven that neural oscillations is elucidating the neural mechanisms between auditory training and the temporal stages of working memory (Yurgil *et al*., 2020). In addition, EEG can detect neural oscillations activity which link to cognitive control processes that found in prefrontal cortex (PFC) (Helfrich and Knight, 2016). In essential, the oscillatory mechanism can facilitate parameter space regions, aspects of WM, introduce neural representations, and rapidly transitioning activation patterns based on selective inputs at once. This way allows researcher to gain further insight by exploring the limitation between populations (Pina *et al*, 2018).

1.2 Problem statement and Rationale of Study

Environmental, genetic and lifestyle factors are all thought to influence cognitive health. Decline in cognition may vary from mild to dementia, a form of decline in abilities which severe enough to interfere with an adult's daily life. Alzheimer's disease is the most common form of dementia (WHO, 2020) . Tey et *al.,* (2016) indicated that the prevalence of dementia suggested to be increased by 0.328% from 2020 to 2050 in Malaysia. The fact that cognitive processing is slowing with age (Lu *et al*., 2011), most family members view the disease symptoms as normal aging (Nuri *et al*., 2017; Rivan *et al*., 2020) where cognitive challenges are associated with deficits in working memory (Morgan and Brown, 2018). WM is important for an individual to learn, realize full potential, cope with life stresses, work productively and allows to make meaningful contributions to the communities. Studying how working memory load affects neural processing in healthy adults particularly, contribute to the understanding on how our cognitive function work, as well coping the capacity of neurological and psychiatric diseases or disorders (US and Study, 2007). For instance, WM component such as attention can be assessed using stimuli in n-back or comparison of the connections to each brain region (Hanouneh *et al.*, 2018). Nonetheless, to the best of our knowledge, these studies are not many in the local context.

To add, decline in WM are linked to the risk of onset of neurodevelopmental disorders such as schizophrenia, and "there is a significant temporal overlap between the peak of first episode psychosis risk and WM maturation" (Andre *et al*., 2015, p.1). It has been viewed that healthy adults "brain activation during all WM tasks in higher order cortices and decreased in more diffuse and potentially more immature neural networks" (Andre *et al*., 2015, p.1). A neural mechanisms of memory control study by Funahashi (2017) also suggested that PFC important mechanisms related to the central executive can be identified through controls memory resource. In this study, we hypothesized that there is no significant difference between theta and gamma neural oscillations during 0 back and increase level of WM load tasks. The variable presence between theory and findings would benefit the communities on the detail of cognition strength and weakness in individual as well improving the efficiency of working memory development as we aged. Such knowledge not only be helpful to reflect the capability of an individual, but the information would be useful to initiate the regulation among learners. Altogether, we hope the finding could provide an insight in improving our lifestyle, knowledge, and benefit for the future.

1.3 Research Questions

i.) What is the characteristic of theta and gamma oscillation during n-back WM tasks in healthy adults?

ii.) Do theta and gamma oscillation show significant differences in the region of interest during 0 back and increase level of n-back WM tasks?

1.4 Objectives

1.4.1 General Objective

To assess the neural processing during easy to difficult level of n-back working memory load task in healthy subjects from EEG data

1.4.2 Specific Objectives

i.) To analyse theta oscillations in the ROI during 0 back and increase level of n-back WM load tasks.

ii.) To compare theta oscillations in the ROI during 0 back and increase level of n-back WM load tasks.

iii.) To determine gamma oscillations in the ROI during 0 back and increase level of n-back WM load tasks.

iv.) To compare gamma oscillations in the ROI during 0 back and increase level of n-back WM load tasks.

1.4 Hypothesis

The study presented null hypotheses as follow:

H_0: There is no significant difference on theta oscillation in the ROI during 0 back and increase level of n-back WM load tasks.

H_0: There is no significant difference on gamma oscillation in the ROI during 0 back and increase level of n-back WM load tasks.

CHAPTER 2

LITERATURE REVIEW

2.1 Working Memory Load

WM load can be defined as the exchange of central attentional processes together with structure of STM to handle many present codes in different temporal storage components (Baddeley, 2012). WM load can be linked with cognitive load although it can be differentiated in terms of definition. To illustrate, Camos (2017) define cognitive load as equal to the length of attentional capture separated by the amount of allowed time when performing the task. Moreover, cognitive load may indicate to its intrinsic and extraneous load while WM load is looking on the low and high load existence. Identically, cognitive load can be linked to the theory of cognitive load (CLT). Mestre (2012) viewed cognitive load theory as a short-term or WM limited ability which can process as much as information efficiently at a time. If WM is overloaded, a person may have trouble with processing that leads to poor judgement and learning (Bergman Nutley and Söderqvist, 2017; Blasiman and Was, 2018; Wiley and Jarosz, 2012). The central attentional control system meantime is presumed to locate mainly in the frontal areas of the brain such as the dorsolateral prefrontal cortex (DLPFC) (Funahashi, 2017; Ligeza *et al*., 2016; Nouchi *et al*., 2020; Thiele and Bellgrove, 2018) while content in STM was expected to be nurtured through parietal areas like the intraparietal sulcus (Scharinger *et al*., 2015) . In addition, increasing of mental workload often shows the same effect outcome in frontal theta activity and reducing parietal alpha activity (Dasari *et al*., 2017; Wang *et al*., 2018) . Yet, past research presented that other mental states can also influence estimation for workload detection. For example, induced fatigue and decrease of working memory load has been found with the increasing time on task discrimination (Grissmann *et al.*, 2017; Zhang *et al.*, 2020).

Baddeley & Hitch (1974) argued that cognition deals with short-term storage, happen in the present time and need to be elaborated in detail. Baddeley and Hitch (1974) presented the three components working memory model which comprises the central executive (CE), the verbal storage mechanism referred to as the phonological loop (link with BA 40 and 44), and the visual storage system called the visuospatial sketchpad (link with BA 6, 19, 40 and 47). Baddeley (2012) further pointed WM major function is to exchange information into a certain cognitive model by utilizing two executive functions (EF) (originally known as "central executive") that in charge on the coordination and manipulation of the information. Other WM studies by (Diamond and Ling, 2016) indicated the core of executive function as inhibition, WM, and cognitive flexibility. (Hugdahl, 2009) divided the EFs components as inhibition, shifting, and updating. However, an extended component of WM which known as an episodic buffer then introduced to serve the abstract representations of events follow up to a new finding (Baddeley, 2012). Hence, WM can be considered as the fundamental of cognitive processes that depend on temporary memory storage (Oberauer, 2019).

In the brain, WM is achieved across an interaction within caudal frontal systems and posterior systems in the extension of information. Separate caudal frontal–posterior system will act based on the sort of information which is preserved (Badre and Nee, 2018; Bakhit *et al.*, 2020; Kim, 2019; Nee and D'Esposito, 2018) . These separations are specifically well reported in spatial, verbal, and visual-object domains (Eriksson *et al.*, 2015). Extended anterior frontal areas in the mid-lateral prefrontal cortex serve to coordinate the operation of caudal frontal–posterior networks by presenting top-down control over the related networks (Ong *et al.*, 2019). The lateral PFC is structured within the network together with rostral–caudal axis as which dominate mechanisms by contextual processes in the rostral areas of the PFC (Badre and Nee, 2018). To sum up, WM can be thought as a four-layer model with processes of which are called as the context (rostral PFC), control (mid-lateral PFC), retention (caudal frontal), and representation (parietal/temporal) positioning within the rostral and caudal area of the cortex (Nee and D'Esposito, 2018).

To manipulate the WM load in a trial or task, a digital memory test can be used with the visual search trial in memory load condition (half of the trials), contrary the no load condition or the other half trials (Wu *et al*., 2019). Other way, use of a cross-modal paradigm (interactions between two or more different sensory modalities) can engage participant in a primary visual WM task on low and high load conditions, while commanded to ignore unrelated auditory stimuli (Simon *et al*., 2016). There is past proof that a concurrent WM load oppositely effect on temporal attention specifically to the effects of attention on possible duration assessment with single versus 0-back dual-task conditions (Polti *et al.*, 2018; Smith and Casteau, 2019). Even though the ability to update working memory is linked to WMC, it remains unclear whether temporal attention was influenced by lack of working memory stores or by limitations imposed by updating WM (Adams *et al*., 2018; Cowan, 2017). A study in healthy young adults address that temporal attention is not affected by available working memory stores. In fact, posterior beta band (12-30 Hz) activity was differently regulated by temporal attention and WM load, as it decreased prior to expected targets and increased with load. The studies further pointed the study among subjects emphasized that greater temporal attention-based modulation of beta activity, demonstrate improved discrimination performance, also tend to exhibit lower working memory accuracy (Zanto *et al*., 2020).

Additionally, WM load can be directed to the level of WM capacity (WMC) and how different types of tasks in the amount of attention required (Radüntz, 2020; Yoon et al., 2016). In the past, WMC is used as a unitary form that can be described by one cognitive mechanism (Gruszka and Ne, 2017; Shipstead *et al.*, 2015; Tiego *et al.*, 2018). Study also observed that multiple mechanisms are required to explain individual differences where multivariate statistical analysis uncovers the WM critical components (Todorov *et al.*, 2020). These mechanisms, nonetheless, not always represented by all WM tasks (Shipstead *et al.*, 2015). For instance, continuous memory test performance indicate that primary memory is better than either complex span or visual arrays tasks. The comparison of these latter trials was said likely linked with a person's attention control and retrieval capabilities (Shipstead *et al.,* 2015). Based on individual differences study, it was suggested that WMC is link to attention and auditory sensory gating (Sörqvist and Rönnberg, 2014). The relationship between distraction and WMC can be described in between different population according to the variables that associate with WMC. For example, age, personality traits and developmental disorder. The study proposed a neurocognitive task-engagement or distraction trade off model which emphasize information and direction.

2.1.1 Working Memory Load effect in Health

Recent study conducted in healthy subject showed that low WM load is linked with optimal distractor inhibition and increased cardiac control under anxiety (Spangler and Friedman, 2017). The result proposed that under high level of anxiety, the ability to obstruct dominant responses and cardiac vagal control is depend to WMC in controlling the relation of WM load. In schizophrenic subject, a functional MRI study show that they can completed as well as healthy subject although in the most unfavourable load conditions and that no BOLD signal differences were seen at high load (Hahn *et al*., 2020). In comparison with performance of mild cognitive impairment (MCI) control, healthily aging controls showed that they were selectively and significantly higher when tested in the name-location binding (Sapkota *et al.,* 2017).

An eye tracking study conducted by Hasanzadeh *et al.* (2017) on healthy subjects described the significant effect of attentional distributions and hazard-detection performance under low and high WM load conditions. Based on the outcome, it was confirmed that the WM task is effective in manipulating cognitive abilities and their judgement into danger. The great number of missed hazards under the high WM load condition demonstrated that participants' change their attention from unsafe situations and unable to adequately participate to hazards when they were under higher cognitive loads. This result was suggested to mimic the results of Fan *et al.* (2019) where high WM load could cause inattentional blindness or failure to detect related items which can increase the risk of accident. Therefore, WM load can monitor the person's hazard-detection abilities.

2.1.2 Working Memory Load effect in Age

Everyday experience may affect to our working memory capacity. In fact, healthy aging is associated with impair cognitive processing (Ishii *et al.*, 2017). Decline in WM can cause problem in memory, language, thinking or judgment. Increased WM requirements in older adults will likely weaken their sentence processing. (Alatorre-Cruz *et al*., 2018). According to Pliatsikas *et al*., (2019), males showed more WM decline than females with increasing age while females showed greater WM gains than males with increasing education. Together with other findings, they have suggested that age, gender, and level of education have significant impact WM in older adults, in spite the interpretation can be viewed in certain ways. There have been several cases of the efficiency of WM performance in aging. To name one, Weicker *et al.*, (2016) observed minor transference effects to cognitive function and attention, but no transfer to long-term memory or reading comprehension. A recent review by Gavelin *et al.* (2020) discussed that the current situation supports the efficacy of cognition-oriented treatments improving cognitive performance in older adults. Likewise, Soveri *et al.*, (2017) concluded that medium-sized transfer effects to untrained n-back tasks and very small effects to other WM tasks. The n-back analysis nonetheless did not find significant effects of age, training dose, type (single vs. dual), or WM and fluid intelligence (Gf) transfer task contents (verbal vs. visuospatial). A considerable part of exchange following WM training with the n-back task is task-specific and discuss the implications of the results to WM training research.

2.2 N-back

The N-back task has been introduced by Kirchner in 1958 as a visuospatial task with four load factors and developed with up to six load factors by Mackworth in 1959 for visual letter task. N-back tasks are continuous-recognition measures which present the stimulation sequences and allows people to think whether the item is compatible with the one they have seen n items before. For example, images, words, letters, and shapes for each item in the sequence (Coulacoglou and Saklofske, 2017). The load factor n can be altered to change the level of the task and to place the neural substrates underlying WM (Blasiman and Was, 2018; Salminen *et al*, 2020). The n-back task requires at least two different tasks, namely the retrieval of information from the present trial, while at the same time recalling and manipulating information from prior trials (Blacker *et al.*, 2017;