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A Comprehensive Investigation to Identify Working Memory Components Utilizing Thematic Analysis Technique: A Qualitative Research

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Abstract

Background: Working memory (WM) is commonly known as a mediator between short-term and long-term memory. However, WM as well is a data processor and manipulator in charge of a considerable portion of our cognitive abilities. Due to the recently grasped significance of further investigations of WM, this study was conducted aiming to identify the entire WM components present in the current literature utilizing qualitative thematic analysis.

Methods: Stirling's novel method of qualitative inductive thematic analysis was applied to extract the entire components of WM from the current literature up to 2018.

Results: Our results yielded 57 basic concepts (themes) related to WM out of 1099 concepts, which was integrated into 18 organizing concepts that altogether comprise the global notion of WM. Statistical validation was conducted through expert confirmation and content validity index (CVI) calculation (0.88). Moreover, the Holsti coefficient was 0.60 that indicates relatively appropriate reliability.

Conclusion: Considering the growing interest in studying WM components, conducting an integrative research aiming to thoroughly clarify these components was required. Herein, through applying the novel technique of thematic analysis, we have developed a comprehensive theme network designed to facilitate future studies on WM.

Keyword: Thematic analysis; Themes network; Themes template; Themes matrix; Working memory.

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Introduction

Determining the cognitive mechanisms underlying the human learning process has for long been the focus of numerous studies and a considerable part of this process is shown to be mediated through working memory (WM).[1]

Up to 1974 short term memory was merely considered as a mediator between short term and long term memory and less attention was dedicated to its other potential utilizations. However, by Haich and Baddeley's memory model presented in 1974, the notion of short-term memory was expanded and the concept of WM drew the attention of many researchers in the field.[2]

In recent years among all the existing models and schemas in memory, the model of WM has been more approved and applied by psychologists, since this model accounts for various perspectives of both short and long term memory.[3]

WM as well plays a remarkable role in the educational system and is the underlying mechanism for fundamental skills used in the classroom and a crucial tool in different activities of the school.[4,5] Spontaneous data processing is a vital role of WM, which is as well the underlying mechanism for intelligence and a significant predictor of goal achievement.

Former works suggest that WM merely maintains the newest active part of the memory and sends these active elements in and out of the temporary memory storage.[6] WM as well has an important role in behavioral areas, and different life skills, including semantic skills, problem-solving, and mathematical reasoning. Moreover, WM is known as a cognitive system enabling temporary information storage which afterward processes data in cognitive tasks such as reasoning, language comprehension, and decision making.[7] Due to the data processing nature of WM, limited capacity of this form of memory will limit the cognitive functionality,[8] however, this capacity can be enhanced through practice.[9]

WM was as well introduced as a complicated cognitive system for simultaneous data processing and storing, facilitated by WM mediating between perception, long term memory, and behavior.[10] Moreover, the dynamic engagement between keeping memory components

(storing) and attention control is at the service of complex cognitive tasks.[11] According to this notion, WM is a form of instant adaptive memory that enables the person to preserve the related information active and accessible while implementing the task. In agreement with this idea, information storage and mental temporary manipulation of information are indicated to be of WM components.[12] Focus, attention, and expertise are of other mentioned components of WM in the current literature.[13] It has also been suggested that WM is an integrating processor of long term memory with temporary memory.[14]

Current theories about WM derived from functional brain studies and lesion studies describe WM as a network with limited capacity and multiple components that connect various brain centers.[15] Various studies have been conducted to investigate the role of each of these components in cognitive performances, for instance, visuospatial WM is shown to be significantly correlated with a mathematical performance at school.[16] Current trends tend to have a greater emphasis on utilizing more accurate techniques when investigating WM components.[17]

A number of WM components have thus far been investigated separately, however, no prior work has clarified these components. Due to the integrative nature of this research, however, a valid and reliable qualitative method was required to be applied holistically addressing this research question. The thematic analysis technique was first introduced in 2001 by Stirling and has survived so far as an acceptable systematic technique in qualitative research.[18] This is a novel technique used to enhance the data extraction from the related literature and facilitates the presentation of qualitative results through creating a network of themes. This technique has as well found its way to educational curriculums in the field of analytic psychology and other fields requiring qualitative research techniques.[19]

Despite the growing literature on WM, remarkable questions are left to be addressed in this field, namely regarding the role of WM in high-level cognitive processing. Studying features and components of WM is therefore crucial to enrich our understanding of human learning mechanisms. Findings in this regard can be utilized in advancing educational systems, especially for cases with learning disabilities.

Therefore, this study was conducted aiming to identify the entire components of WM in a healthy population by systematically reviewing the current literature in the field and applying Stirling's thematic analysis technique.

Materials and Methods

All studies utilizing standard designs investigating various components of WM in a healthy population up to 2019 were found eligible to enroll in this study, due to the integrative nature of this research.

Studies were only excluded if they have not been indexed in scientific databases or have not been written in English or Farsi.

Stirling's method of qualitative inductive thematic analysis was applied to identify various WM components and categorize them into global, organizing, and basic themes. This network illustrates the data extracted qualitatively from the literature and eases the data exploration process.[20]

The required steps for performing the above-mentioned analysis technique were respectively as follows:

1. Breaking down the included text
- Coding the text through recognition and explanation of the desired sections of the text and color coding
- Defining the themes that are included in the abstracts and categorizing them into three groups: global, organizing, and basic (these categories are later used to design the themes network, i.e. the basic theme is the most basic or the lowest type of themes that is obtained from textual data and is the beliefs and supportive viewpoints of a central concept. Integrating a number of basic themes create an organizing theme that is more abstract and eventually global themes that are highly coordinated and are a set of organizing themes.
- Creating a theme network, which is an illustrated display of the above-mentioned three themes.

2. Exploring the texts
- Describing and exploring themes network
- Summarizing themes network

3. Refining the central conceptual findings in themes network

Applying this method when searching for WM components, 20 English scientific references (including both books and scientific papers) and 77 references in Farsi were included in the study (including both books and scientific papers). Literature was thoroughly investigated until no more related study was found and any study investigating WM components in a healthy population was already included in the study.

After initial inclusion based on title and abstracts, full manuscripts were reviewed for the extraction of basic themes through text coding, and related sentences and paragraphs were extracted. Afterward, listing and clustering of these themes were conducted, and the basic themes were integrated to create organizing themes. This integration process was according to the content and common theoretical bases and similarity of the subjects. From integrating the organizing theme, one global theme which is the WM theme was generated.

The validity of our method was evaluated by ten specialists in the field of WM, checking the themes network and content template. Experts were asked to if necessary, express their feedbacks concerning each theme before finalizing the themes network.

Afterward, the content validity index (CVI) and holistic reliability coefficient were calculated based on the level of agreement between experts and the authors.

Also, based on the frequency and the repetition of each theme in the themes network, themes matrix was drawn to be used for comprising themes with each other and their internal relation based on frequency level. In this matrix, the relationship between each obtained basic theme can be explored in regard to other themes using frequency analysis.

Results

At initial evaluation for extracting the concept codes, 1099 concept codes were extracted, among which 384 concepts were related to WM. After qualitatively analyzing the concepts, 57 were categorized as the basic themes, 18 as the organizing themes, and one global theme (working memory). Table 1 illustrates each of these themes.

Qualitative validity analysis was conducted and the CVI was calculated (0.88). The reliability coefficient of this themes template was calculated by holistic method using the following formula:

$PANO = 2\ M/(n_1+n_2)$

PAO: observed agreement percentage or reliability coefficient

M: the number of agreements between chosen themes by researcher or experts group

n_1: the number of coding units by the researcher

n_2: the number of coding units by experts group

Eventually, PAO was calculated 0.6 that indicates appropriate reliability.

The above themes are illustrated in our theme network and theme matrix (Figures 1 and 2).

Figure 2 represents the internal relations of each WM component based on the frequency of the basic components. According to this matrix, the basic WM component "effective on reading" is more related to the component "effective on complex cognitive abilities" based on frequency analyses rather than with the components of "attentional supervisory controller", "interference inhibition controller", and "visuospatial plan predictor". Moreover, the component of "effective complex cognitive abilities" is more associated with the "dependent to individual difference" component than "effective on mathematics" components. Also, "working memory feature" and "working memory function mechanism" are two basic components that are mostly related to "attention supervising controller", "interference-inhibition controller", "updating", "intelligence element", "working memory proprietary subsystem", "time processing", "educational", and "mediator working memory". The "attentional–supervising controller" and "interference –

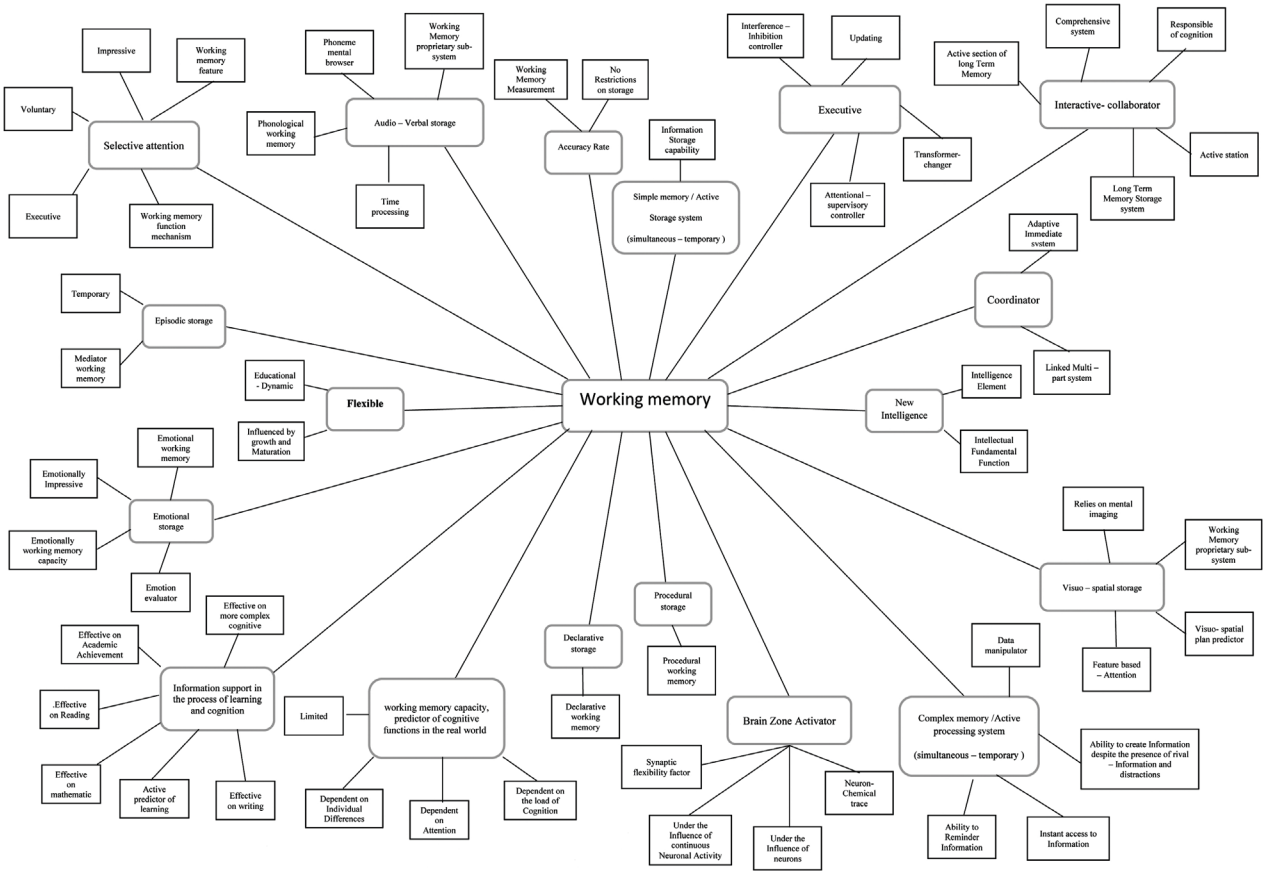

Figure 1. Working Memory Themes Network

Table 1. Working Memory Themes Template With the Frequency of Themes

Frequency	The Basic Themes	The Organizing Themes	The Global Themes
10 7	1. Intelligence Element 2. Intellectual Fundamental Function	1. New Intelligence	Working Memory
6 6 3 7	3. Dependent on Attention 4. Dependent on Individual Differences 5. Dependent on the load of Cognition 6. Limited	2. working memory capacity, a predictor of cognitive functions in the real world	
1 4	7. Educational- Dynamic 8. Influenced by growth and Maturation	3. Flexible	
7 3 3 6 5	9. Comprehensive system 10. Responsible for cognition 11. Active station 12. The active section of long Term Memory 13. Long Term Memory Storage system	4. Interactive- collaborator	
5 3	14. Adaptive Immediate system 15. Linked Multi-part system	5. Coordinator	
3 3	16. No Restrictions on storage 17. Working Memory Measurement Index	6. Accuracy Rate	
4 6 5 8	18. Under the Influence of neurons 19. Under the Influence of continuous Neuronal Activity 20. Synaptic flexibility factor 21. Neuron- Chemical trace	7. Brain Zone Activator	
10 4 5 9 11 8	22.Effective on Reading 23. Effective on writing 24. Effective on mathematics 25. Effective on Academic Achievement 26. Effective on more complex cognitive abilities 27. Active predictor of learning	8. Information support in the process of learning and cognition	
9 22 13 10	28. Transformer- changer 29. The attentional – supervisory controller 30. Interference – Inhibition controller 31. Updating	9. Executive	
4 6 6 7	32. Ability to Reminder Information 33. Ability to create Information despite the presence of rival – Information and distractions 34. Instant Access to Information 35. Data manipulator	10. Complex memory /Active processing system (simultaneous – temporary)	
7	36. Information Storage capability	11. Simple memory/Active Storage system (simultaneous – temporary)	
8 13 5 8 7	37. Working memory feature 38. Working memory function mechanism 39. Impressive 40. Voluntary 41. Executive	12. Selective attention	
4 13 5 7	42. Working Memory proprietary sub-system 43. Visuospatial plan predictor 44. Feature-based – Attention 45. Relies on mental imaging	13. Visuospatial storage	
6 20 8 9	46. Working Memory proprietary sub-system 47. Time processing 48. Phoneme mental browser 49. Phonological working memory	14. Audio – Verbal storage	
9 4 6 4	50. Emotionally Impressive 51. Emotionally working memory capacity 52. Emotion evaluator 53. Emotional working memory	15. Emotional storage	
12 5	54. Mediator working memory 55. Temporary	16. Episodic storage	
5	56. Procedural working memory	17. Procedural storage	
4	57. Declarative working memory	18. Declarative storage	

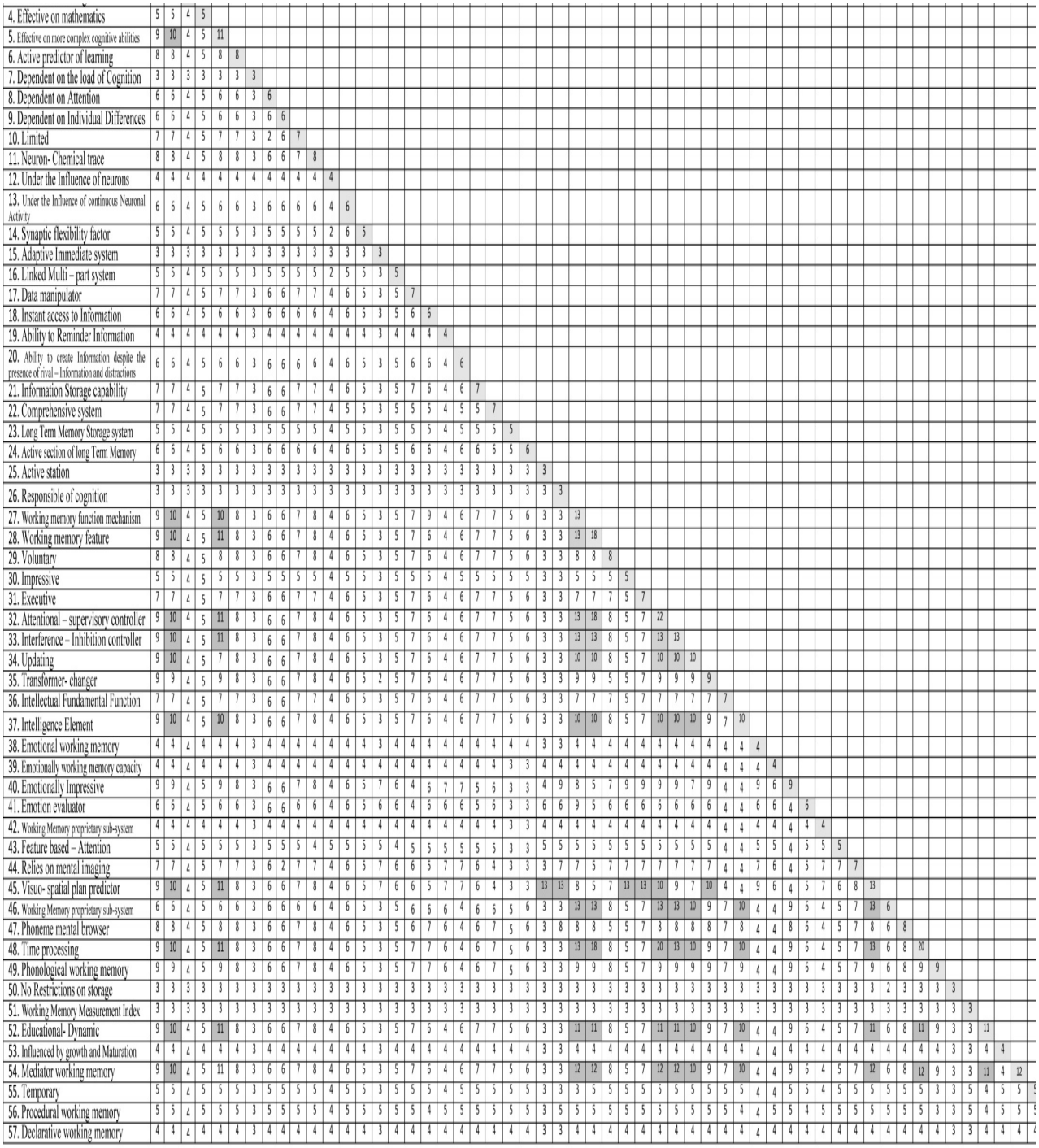

Figure 2. Working Memory Themes Matrix.

inhibition controller" components are highly associated with "updating", "intelligence element", "working memory proprietary subsystem", "educational", and "mediator working memory". "Intelligence element" is primarily related to "visual buffer" that consists of "working memory proprietary subsystem", "time processing", "educational" and "mediator working memory". "Working memory measurement index" is regularly related to "educational", "mediator working memory", and "temporary" to "mediator working memory". Eventually, the "Intelligence element" and "intellectual fundamental function" components are mostly associated with the "visuospatial plan predictor" component.

Discussion

This study was conducted aiming to identify the entire components of WM present in the current literature through qualitative thematic analysis.

WM in general is in charge of active data processing and information manipulation, and therefore, is the underlying mechanism enabling many of our cognitive abilities. Defining and identifying the components and themes of WM is based on models' perspectives derived from working memory.

WM is primarily explained through three models[21]: Leon Pascual's developmental model (1975), Coawn's cognitive neuropsychological model (2011), and Haich and Baddeley's educational cognitive model (1974-2006).

Haich and Baddeley's model of WM is widely referred to for theoretical explanations of organizing themes: visuospatial buffer, audio-verbal, episodic, executive, and emotional.[22] Baddeley's WM model not only has been surveyed frequently in educational literature but also has been used as an academic achievement predictor.

Cowan's model (2011) presents a biological mechanism to explain the role of WM in learning. This model considers attention as a dependent variable regarding WM. Actually, according to Cowan's model, attention and especially selective attention are in the center of stimuli' processing and support attentional focus in association with capacity extent or saving extent in working memory. According to Cowan's idea, attention comes from a different neuro-psychological view that explains biology mechanisms of brain neural networks, consequently, organizing themes of selective attention and activities of brain regions are related to Cowan's idea.

Pascual's model (1975) is a growth model that unlike Baddeley's model, is not widely used in research and education. This model shows how the WM works in children and how its processing changes as they grow up.[23] Pascual's model is based on the activity of the learning period and shows the amount of man's learning and doesn't show the process or biological changes that happen in making the brain while learning. Pascual's model indeed shows cognitive thinking capacity that is both under the influence of education and growth and maturation period, consequently is related to organizing themes of flexibility and cognitive activities of working memory.

While checking the reliability of our method, the indices of the percentage of agreement (PAO) was calculated 0.60, which represents appropriate reliability. Moreover, validity was examined through CV indices calculation which was 0.88 and is as well appropriate validity (compared to the standard number of 0.79).

Based on the illustration in our themes network (Figure 2), WM can be described as a structure underlying information processing that constructs learning and cognition. This notion is in alignment with former findings, particularly the outstanding study conducted by Ramus in 2001, examining phonological processes in dyslexia,[24] suggesting that "reading ability" as a component of WM is involved in decoding the text words, reading speed and comprehension, in addition to phonological defects in case of working memory deficit and defective attention functions.[25,26]

Baddeley categorizes WM functions in four components: Central executive factor that is a general scope regulators component, useful for allocation of attentional sources and in charge of many regulatory functions such as cognitive coordination in simultaneous multiple activities, engaging sources to other components of WM and retrieving information from long term memory. In this pattern, a temporary saving of information is conducted with two special storage. One is the phonological loop, responsible for the temporary saving of verbal information and the other is the visuospatial sketchpad that is responsible for keeping and manipulating the visuospatial representation. The fourth component in Baddeley's theory is episodic mediator memory that is responsible for converting memory subsystems and information dimensions to integrated parts.[27] All of these components are embedded in our theme network explaining the holistic nature of WM.

Moreover, WM is a system that is responsible for processing and saving temporary information and is necessary for high-level cognitive functions and better setup of emotional experience.[28] To include the role of emotion effect in presenting a comprehensive model of WM, another component, termed hedonic detector was later introduced by Baddeley.[29] This component is involved in assessing sophisticated situations with value level and valuate existing representations in episodic mediator memory as positive and negative.

Of other remarkable WM functions is being a powerful predictor of fluid intelligence. Conway considered fluid intelligence and WM as being a unit system and entitled fluid cognition. However, WM is primarily recognized as a cognitive system with limited capacity that stores information and simultaneously manipulates them.[30] In this regard, Hornung considered selective attention to be of other WM functions, that is the ability to merely attend to a portion of information and ignore the other portion, and is crucially important in the function of WM executive system.[31] In other words, it can be said that selective attention refers to the ability of avoiding irrelevant information regarding the task and choosing the specific information.[32] What is clear is that selective attention is one aspect of inhibition control. Distraction, defined as an inability in accurately focusing on a special stimulus and exploring a sophisticated stimulus effectively, is another problem that usually occurs in people with selective attention deficit.[33]

In summary, it is to be said that WM has so far been modeled through different perspectives, however, the presence of its multiple components identified in this research must be considered to enable presenting an integrative theory. These extracted components as well can

be used in future studies, enabling researchers to specify the component of WM that is important in their research. For instance, when exploring learning difficulties, it is more exact to consider the WM components that are related to learning and academic achievements or when we investigate hyperactivity or attention and concentration deficits, the WM components related to executive control should be studied.

But what is apparent is that we should not ignore some components for mere attention to one or more components. According to the presented working memory themes network in this study, suggest that to improve and strengthen the working memory as an important cognitive capability of man in life, at first pay attention to views, strategies, and existing conditions and then by analyzing and thinking about them, consider the other dimensions and criteria that comprehensive working memory improvement. Also, it suggested that due to the impact's share of working memory in some psychological and neuropsychological disorders, all of the elements and components of working memory covered in a way that can investigate working memory components that are related to the kind of disorder in different conditions.

In conclusion, according to the qualitative findings of this study, the specification of WM components derived from our study can remarkably enhance future studies in this field. As a general limitation, it should be said that the results of qualitative studies cannot easily be generalized, therefore, future works are required to further define each of these WM components, particularly in regard to potential neural correlates.

Conflict of Interest Disclosures

The authors declare that they have no conflict of interests.

Ethical Statement

Regarding the ethical concerns, a systematic approach was applied to avoid personal biases. The comments of the experts who were consulted for confirming the validity and reliability of our method were analyzed anonymously to maintain objectivity. Also, a comprehensive and integrative approach was used to elude selection bias when including the studies.

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