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INTERACTIONS BETWEEN WORKING MEMORY AND CREATIVITY: A SYSTEMATIC REVIEW

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ABSTRACT. Creativity and working memory are academic and professional success markers. Paradoxically, correlational studies do not always find associations between these constructs; some studies show positive associations between them and others show negative associations. Probably, the contradictory findings arise from different parameters, because of that it is important to identify them in order to have a more coherent understanding of this relationship. Thus, this systematic literature review aimed to answer the questions: "What is the relationship between working memory and creativity? Do update and serial recall mnemonic processes also interfere in the production of convergent or divergent thinking?" For this purpose, a survey of specific descriptors generated 384 articles found in Scopus, Web of Science and Pubmed databases, from which fifteen studies were selected. Despite the methodological variability between the selected studies, the results found suggest association between working memory and creativity, which are explained by the attentional, inhibitory, analytical and motivational processes involved. A systematic review of these studies concluded that the characteristics of experimental tasks to study creativity and working memory used can influence the results of this association. It is also possible to infer that working memory overload can impair creative performance.

Keywords: Working memory; creativity; divergent thinking.

INTERAÇÕES ENTRE MEMÓRIA OPERACIONAL E CRIATIVIDADE: REVISÃO SISTEMÁTICA

RESUMO. A criatividade e a memória operacional são marcadores de sucesso acadêmico e profissional. Paradoxalmente, estudos correlacionais nem sempre encontram associações entre esses constructos, algumas pesquisas evidenciam associações positivas entre os mesmos, e outras, associações negativas. Provavelmente, os achados contraditórios decorrem de parâmetros distintos, sendo importante identificá-los para uma compreensão mais coerente de tais relações. Assim, esta revisão sistemática de literatura teve como objetivo responder às questões: "Qual a relação entre memória operacional e criatividade? Processos mnemônicos de atualização e de recordação serial interferem igualmente na produção de pensamento convergente ou divergente?" Para tanto, um levantamento com descritores específicos gerou 384 artigos encontrados nas bases de dados da *Scopus*, *Web of Science e Pubmed*, dos quais, foram selecionados 15 estudos. Apesar da variabilidade metodológica apresentada entre os estudos selecionados, os resultados encontrados sugerem associações entre memória operacional e criatividade, que se explicam pelos processos atencionais, inibitórios, analíticos e motivacionais envolvidos. A revisão sistemática desses estudos permitiu concluir que as características das tarefas experimentais para estudo da criatividade e de memória operacional utilizadas podem influenciar nos resultados obtidos de tal associação. Depreende-se, também, que a sobrecarga de memória operacional pode prejudicar o desempenho criativo.
Palavras-chave: Memória operacional; criatividade; pensamento divergente.

LAS INTERACCIONES ENTRE LA MEMORIA OPERATIVA Y LA CREATIVIDAD: UNA REVISIÓN SISTEMÁTICA

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RESUMEN. La creatividad y la memoria operativa son marcadores académicos y profesionales de éxito. Paradójicamente, los estudios de correlación no siempre encuentran asociaciones entre estos constructos; algunos estudios muestran asociaciones positivas entre ellos y otros muestran asociaciones negativas. Probablemente los hallazgos contradictorios surgen de diferentes parámetros, por lo que es importante establecer una comprensión más coherente de tales relaciones. Por lo tanto, esta revisión sistemática de la literatura tiene como objetivo responder a las preguntas: "¿Cuál es la relación entre la memoria operativa y la creatividad? Los processos de actualización mnemónica y recuerdo serial afectan también la producción de pensamiento convergente o divergente?" Con este fin, una encuesta de descriptores específicos genera 384 artículos que se encuentran en las bases de datos Scopus, Web de Ciencia y Pubmed, de los cuales se seleccionaron 15 estudios. A pesar de la variabilidad metodológica presentada entre los estudios elegidos, los resultados sugieren asociaciones entre la memoria operativa y la creatividad, que se explican por los procesos de atención, inhibitorios, de análisis y de motivación en cuestión. La revisión sistemática de estos estudios concluyó que las características de las tareas experimentales para el estudio de la creatividad y la memoria operativa utilizadas pueden influir en los resultados de una asociación de este tipo. De ello se deduce, también, que la sobrecarga de memoria operativapuede dañar el rendimiento creativo.

Palabras-clave: Memoria operativa; la creatividad; pensamiento divergente.

Introduction

Creativity has been considered important for professional success, especially in the areas of economic knowledge and technology (Yeh, Lai, Lin, Lin, & Sun, 2015), and is valued in different fields of knowledge such as medicine, science, engineering, arts and law (Pfeiffer & Wechsler, 2013). According to recent studies, this ability can be trained and developed through teaching and practice, especially through programs and strategies aimed at fostering creative thinking (Nakano, 2015). These applied aspects seem well established, however the conceptualization of such a construct may vary among authors.

Sternberg and Lubart (1999) define creativity as idea generation or new solutions to problems in an appropriate way. Runco and Jaeger (2012) relate the term to the novelty and usefulness of the information generated, both in relation to behaviors and activities and the ability to produce ideas with these characteristics. Other authors such as Prieto, Soto and Vidal (2013) refer that creativity is related to divergent thinking, which consists of generating a wide range of solutions; and contrasts with the convergent thinking, which selects the most appropriate alternatives in order to solve a problem.

However, the evaluation of creative processes is complex and demands different resources, for instance, Pinheiro (2013) proposes eight groups of measures of creativity: i) tests of divergent thinking; ii) inventories of attitude and interest; iii) personality inventories; iv) biographical inventories; v) designation by teachers, peers and supervisors; vi) product judgment; vii) eminence and viii) self-registration of creative achievements, which “are the most used in research even today” (Pinheiros, 2013, p. 99). Most studies adopt measures of divergent thinking developed by Joy Paul Guilford and disseminated by Ellis Paul Torrance as a parameter to evaluate both creativity and diversity of creative traits (Primi, Nakano, Morais, Almeida, & David, 2013).

According to Guilford (1967), divergent thinking considers the three main capacities of creativity: fluency (producing different responses), flexibility (producing responses from different categories), and originality (producing rare responses). From this conception, García, Gómez and Torrano (2013) consider that the Torrance Test of Creative Thinking is prototypical for evaluating fluency (quantity of ideas), flexibility (variety of ideas), originality (singularity) and elaboration (quantity of details).

Neurophysiological studies of creativity that measure the bioelectrical activity generated by the brain, spinal cord, nerves and muscles, apparently do not yet present conclusive evidence on the specific neural basis of creativity. Abraham, Pieritz et al. (2014) are cautious in this matter, given the heterogeneity in the type of tasks used and the questionable effectiveness of the comparison within tasks employed, which make generalizations impossible. By contrast, neuroimaging studies on creativity, which are focused on the organization of neural cells and their functional circuits activated to process information and mediate behavior, have contributed to identify the neural substrate of creative thinking (Colombo, Bartesaghi, Simonelli & Antonietti, 2015). For instance, recent studies (Kleibeuker et al., 2013) have shown the role of the prefrontal cortex in creative processes, in areas reciprocal to those activated by working memory (WM) tasks. In fact, Damasio (2001) emphasizes that WM is crucial

for creative thinking, because it allows an individual to maintain in his mind the knowledge that is relevant to solve a given problem. Possibly, this mediation occurs because WM interacts with several cognitive processes (Mota, 2000).

WM can be defined as the cognitive ability used by a person to process and maintain newly acquired information, in an active state, while performing other cognitive activities (Baddeley & Logie, 1999; Baddeley, 2007). It is, therefore, an extremely important ability for an effective learning, especially during neurodevelopment and in an academic context (Santos et al., 2012; Alloway, 2006; Gathercole et al., 2004).

Different tasks can be used to evaluate WM components, such as span tasks related to serial recall process, e.g. sequences of digit, words, symbols, etc. – when the participant is asked to repeat the stimuli, in the same order or in the reverse order, immediately after having heard or seen them (Uehara & Landeira-Fernandez, 2010) – and the n-back tasks related to the update process (updating) – in which responses are required when the presented stimulus (visual, auditory or spatial) is equal to the target presented "n" times before (Santos, 2005), thus the nature of the tasks used reveals different cognitive processes related to WM.

Recent studies on the interface between WM and creativity have produced antagonistic opinions. Several of them identify an association between these two constructs. However, some demonstrate positive associations between WM tasks and creativity (e.g. Oberauer, Süss, Wilhelm, & Wittmann, 2008; Yeh et al., 2015). While other authors have found a negative association between some processes of creativity and WM (e.g. Wiley & Jarosz, 2012; Lin & Lien, 2013), in this case, the efficiency of the former would imply a limitation of the latter. Finally, there is at least one study that suggests the inexistence of association between the two items through applied tests (Furley & Memmert, 2015).

The most plausible explanation for these disagreements between studies are conceptual and methodological differences. In order to understand such discrepancies, the characteristics of the studies should be analyzed, such as sample (characteristics of the participants), experimental design (cross-sectional versus case-control study) and procedure (biological parameters or behavioral measures used to evaluate the association between WM and creativity), that is, it is crucial to consider the methodological heterogeneity. Therefore, a more precise understanding of what conditions determine the presence or absence of an association between creativity and WM requires a reflection on a set of studies about the subject.

The present study is an effort to answer the following questions: What is the relationship between working memory and creativity? Do mnemonic processes of updating and of serial recall interfere identically with the production of convergent or divergent thinking? As a method to answer such questions, we adopt the systematic review, aiming to present researches that can help to answer the selected guiding questions, establishing a connection between the descriptors and pointing out what is already known about the influence that one can exert on the other.

Method

This systematic review of literature, descriptive and informative, sought to select articles relevant to this research in order to communicate its results and implications (Petticrew & Roberts, 2006). Thus, after the formulation of the guiding questions, the following steps were taken: location and selection of studies in databases; critical evaluation of studies; data collection; analysis, presentation and interpretation of data (Bento, 2014).

The descriptors used were "creativity" and "working memory" and "criatividade" and "memória operacional". The search for these descriptors occurred on the Capes database (which houses other databases such as Scopus and Web of Science) and Pubmed. The research and the selection of the manuscripts were carried out by the first author and reviewed by the second author without any discrepancy between them.

Three hundred and thirty-six articles were found on Capes database and sixty articles were obtained browsing Pubmed in March 2016. After comparing the data, it was verified that thirteen articles

from Pubmed were not available on the portal of Capes. Thirty-four articles from Pubmed appeared only once in the list obtained on Capes and thirteen articles were duplicated.

To check if the articles found during the consultation on the Capes database were related to the theme, it was verified whether the search descriptors were in the title, abstract, or in the keywords of the articles. After this verification, 36 articles were selected for complete reading.

Among the 36 articles found through the consultation on the Capes portal, 8 were inserted in this review because they are empirical researches with the same focus of our analysis: relating creativity to working memory. The others were excluded from this review for the following reasons: they do not relate the descriptors or superficially mention one of them (7 articles), bibliographic reviews (13 articles), pathology or disorder as the main focus of the study (4 articles), pharmachology as the main focus of the study (2 articles), they were found repeatedly (2 articles).

In the Pubmed consultation, all abstracts of 60 articles found were read. From this reading, it was decided to insert only 7 papers. The others were excluded from this literature review for the following reasons: they do not relate the descriptors or superficially cite one of them (23 articles), bibliographic reviews (24 articles), pathology as the main focus of the study (2 articles), experimental drug as the main issue of the study (1 article), they were already included in the review through the search carried out first on the Capes portal (2 articles). It was observed at this stage that most articles had young adults as the target public. For this reason, in order to obtain a more homogeneous analysis we chose to restrict the age group, the reason why a study with participants aged 10-17 years was not inserted based on the age group criterion.

Thus, this systematic literature review focused on the analysis of 15 articles related to the descriptors, in English, “creativity” and “working memory”, found on the Capes and Pubmed databases. It should be noted that all articles that met the established criteria were included in this article regardless of their year of publication.

Results and discussion

In order to extract a maximum of information relevant to the comparison between studies, the data were divided into four categories, the first one regarding the structural characterization of the studies found for the systematic review, the second one addresses the characteristics intrinsic to the methodology of the studies, the third concerns the scientific findings and the fourth examines these findings in terms of the cognitive processes involved in the relationship between creativity and working memory.

Structural characterization of the studies selected for review

A consultation of the quartiles of the journals in which they were inserted was done through the SCImago Journal & Country Rank (available at http://www.scimagojr.com/). It was considered the ranking for the last five years of publication, focusing on the areas of psychology or neuroscience for journals with different areas of approach. The following results were obtained: thirteen articles were published in Q1 journals (Takeuchi, Taki et al., 2011; Takeuchi, Taki, Sassa et al., 2011; Dreu, Nijstad, Baas, Wolsink, & Roskes, 2012; Aziz-Zadeh, Liew & Dandekar, 2012; Roskes et al., 2012; Lin & Lien, 2013; Lee & Therriault, 2013; Abraham, Thybusch et al., 2014; Benedek, Jauk, Sommer, Arendasy, & Neubauer, 2014; Yeh, Lai, Lin, Lin, & Sun, 2015; Furley & Memmert, 2015; Hao, Yuan, Cheng, Eang, & Runco, 2015; Tan, Zou, Chen, & Luo, 2015). There was only one article in Q2 (Razumnikova, 2007) and another in a journal classified as Q2 for most of the years but dropped in the rank to Q3 in 2014 (Lavric, Forstmeier, & Rippon, 2000).

Regarding the chronology of the selected journals, indicated in the references of the presente study, it is noticed that the first article expressing the relationship between WM and creativity was of 2000, by Lavric, Forstmeier and Rippon. The topic was retaken in 2007 with Razumnikova and has had its greater prominence in the last five years, with two publications in 2011 (Takeuchi, Taki, Hashizume et al., 2011; Takeuchi, Taki, Sassa et al., 2011), three in 2012 (Dreu et al., 2012; Aziz-Zadeh, Liew &

Dandekar, 2012; Roskes et al., 2012), two in 2013 (Lin & Lien, 2013; Lee, & Therriault, 2013), two in 2014 (Abraham, Thybusch et al., 2014; Benedek et al., 2014) and four in 2015 (Yeh et al., 2015; Furley & Memmert, 2015; Hao et al., 2015; Tan et al., 2015). It should be noted that, until the date the search was performed, no articles with the descriptors “working memory” and “creativy” published in 2016 were found.

The origin of the works is also very diverse, 3 works from North America (Lavric, Forstmeier, & Rippon, 2000; Aziz-Zadeh, Liew, & Dandekar, 2012; Lee, & Therriault, 2013), 6 from Asia (Takeuchi, Taki, Hashizume et al., 2011; Takeuchi, Taki, Sassa et al., 2011; Lin & Lien, 2013; Yeh et al., 2015; Hao et al., 2015; Tan et al., 2015), 5 from Europe (Dreu et al., 2012; Roskes et al., 2012; Abraham, Thybusch et al., 2014; Benedek et al., 2014; Furley & Memmert, 2015) and 1 from Eurasia (Razumnikova, 2007). From full reading of the articles, the fundamental aspects of the analyzed studies were organized in the following topics: participants, material, objectives, results and study design, which are presented in Tables 1 and 2.

Table 1 - Behavioral, neuroimaging and electrophysiology studies on the relationship between WM and creativity.

Article	Participant	Material	Objective(s)	Results	Experimental Design
Lavric, Forstmeier, & Rippon, 2000.	20 undergraduates (control) and 26 participants (experimental).	Deontic version of Wason's selection task; Two strings problem; The candle problem	Verify if creative insight problems require less planning and WM than analytical problems.	Creative processes are less dependent on WM than analytical processes.	Case control study.
Razumnikova, 2007.	39 students.	SAT and RAT (Russian version) with Verbal Tasks concomitantly monitored by electroencephalograms.	Identify the cortical neural networks that cooperate in creativity during the formation of new verbal associations.	Verbal creativity was characterized by more pronounced functional activity in the left hemisphere and prefrontal cortex.	Cross-sectional quantitative study.
Takeuchi, Taki, Hashizume et al., 2011.	63 participants.	S-A creativity test; RAPM; Computerized forward and backward digit span; 2-back task.	Investigate how creativity relates to brain activity during WM.	Positive relationship between creativity scores and brain activity of the *2-back task* in the precuneus.	Cross-sectional quantitative study.
Takeuchi, Taki, Sassa et al., 2011.	55 university students or post-graduates.	RAPM; Arithmetic task and digit symbol task of the WAIS-III; Letter span task; Processing speed task; Stroop task and S-A creativity test.	Investigate the effects of mental calculation training on WM tasks.	After the intervention, there was improvement in the performance of *letter span tasks* and complex arithmetic tasks and lower scores in tasks of creativity.	Study with control and placebo groups.
Aziz-Zadeh, Liew & Dandekar, 2012.	17 architects or architecture students.	Creative visual task and Control mental rotation task.	Investigate brain activity while performing tasks of visual creativity.	Relationship between WM processes and the motor planning component of creative improvisations.	Cross-sectional quantitative study.
Abraham, Thybusch et al., 2014.	28 undergraduates.	Start uses/ End use of objects; Object-Location task; 2-back task; 1-back task.	Explore differences between the sexes in the brain areas recruited.	Divergent thinking activated different brain areas between men and women; who were similar in the WM task and in the difficulty in accomplishing the tasks.	Cross-sectional quantitative study.

Source: elaborated by the authors. Description of acronyms: RAPM: Raven's Advanced Progressive Matrices; RAT: Remote Associates Test; SAT: Simple associates task; WAIS: Wechsler Adult Intelligence Scale; WM: Working Memory.

Table 2 - Cognitive studies on the relationship between WM and creativity.

Art.	Participants	Material	Objective(s)	Results	Experimental Design
Dreu et al., 2012.	Exp.1: 144 ugrd, Exp.2: 121 ugrd, Exp.3: 32 semi-professional cellists Exp. 4: 60 ugrd.	Exp.1: Resolution of creative insight problems, RAT and WM tasks (digit retention); Exp.2: delayed serial recognition task, RAPM, RAT.; Exp.3: creative improvisation test and tests of the previous study; Exp.4: tasks of generation of creative ideas (Brainstorm task) and OSPAN.	Elucidate the role of WMC in creativity and the mechanisms related to creative performance.	Positive relationship between WM and creativity (creative fluency and originality). WM facilitated the performance of creative insight. Individuals with high WMC had their creative performance increased over the trials and the opposite occurred in individuals with low WMC.	Quantitative cross-sectional study.
Roskes, Dreu, & Nijstad, 2012.	Exp.1: 78 stdt; Exp.2a: 71 stdt; Exp.2b: 69 stdt; Exp.3: 81 stdt; Exp.4: 143 stdt.	Exp. 1: Generation Task (ideas about environmental protection) and word puzzle; Exp. 2: Elaboration of original ideas from two word puzzles; Exp. 3: Two tasks: the first task was functional for the resolution of the second one; Exp. 4: RAT; Mouse-in-maze task with cognitive load manipulation.	Evaluate the effects of motivation on functionality and creative performance.	The functionality of the task stimulated creativity, especially in the motivated group. It produced more unique solutions to problems of creative insight.	Quantitative study of random distribution.
Lin & Lien, 2013.	Exp. 1: 94 ugrd; Exp. 2a: 55 ugrd; Exp. 2b: 68 ugrd.	Exp. 1: 2-4-6 task and CVCTT; Exp. 2a: The same and Chinese reading span test associated with CVCTT (verbal) and Exp. 2b: Insigth-problem task (math problem and four problems of creative insight), OSPAN and CVCTT (verbal).	Examine WM functions in the process of divergent thinking and problem solving tasks.	The increased WM load reduced the generation of creative hypotheses and hampered the performance of the task 2-4-6. There was a correlation between performance in problems of creative insight and WMC. WM did not correlate with divergent thinking.	Exp.1: case control./Exp.2: quantitative cross-sectional study.
Lee & Therriault, 2013.	265 university students.	Symmetry Span task; Backward Digit Span task; Letter fluency task; Category fluency tasks; Unusual Uses Test; ATTA; RAT; Insight problems; WAIS-R, Vocab and RAPM.	Examine whether MO predicts associative fluency, divergent and convergent thinking.	WM predicted associative fluency and convergent thinking, but did not predicted divergent thinking. WM facilitated divergent thinking by generating and analyzing different ideas simultaneously.	Quantitative cross-sectional study.
Benedek et al., 2014.	230 native speakers of German.	2-back task; Number-letter task; Stroop color-word-interference task; INSBAT; DT tasks and Big-Five personality NEO-FFI.	Evaluate executive functions and their relationships with fluid intelligence and creativity.	Update and inhibition tasks predicted creativity, but alternation tasks did not it. These two abilities regulated the generation of creative thinking.	Quantitative cross-sectional study.
Yeh et al., 2015.	102 university students.	SCT; SWMT; Inventory of three-dimensional emotions and evaluation of the cortisol concentration of the participants via ELISA.	Investigate the effect of stress, emotions, WM and creativity in games.	Participants with high WMC presented greater creativity than those with medium and low WMC.	Case control study
Furley & Memmert, 2015.	61 professional soccer players.	Automated operation span score, and adaptation of the soccer-specific divergent thinking test (in offensive soccer scenes).	Investigate the relationship between WMC and creativity in professional football players.	The relationship between WM and convergent thinking was not significant in soccer decision making.	Quantitative cross-sectional study.
Hao et al., 2015.	90 graduated stdt.	AUT (through written and oral answers) and Reading Span Task.	Investigate the generation of creative idea and its interaction with the WMC.	People with high WMC generated more ideas than those with low WMC in writting condition but with no difference in oral condition.	Quantitative cross-sectional study.
Tan et al., 2015.	91 Chinese university students.	NRT (Insight Problem Task), OSPAN, Daydreaming Frequency scale and Divergent Feeling Scale.	Investigate the role of "mind wandering" in solving insight problems.	People who exhibited insight rated themselves as more creative and reported more *mind wandering* than those without it. There was no difference between them in WM.	Quantitative cross-sectional study.

Source: elaborated by the authors. Description of acronyms: ATTA: Abbreviated Torrance Test for Adults; AUT: Alternative Uses Task; CVCTT: The Chinese Version of Creative Thinking Test; DT: Divergent Thinking Task; Exp.: Experiment; INSBAT: Intelligence Structure Battery; NEO-FFI: NEO Five-Factor Inventory; NRT: Number Reduction Task; OSPAN: Mathematical operations and word memorization; RAPM: Raven's Advanced Progressive Matrices; RAT: Remote Associates Test; SCT: Situation-based Creativity Task; stdt: Students; SWMT: Situation-based WM Task; WAIS-R, ugrd: undergraduate students; Vocab: Weschler Adult Intelligence Scale-Revised, Vocabulary; WMC: Working Memory Capacity.

Methodological characterization of systematic review studies

Participants

It is noticed that there was a predominance of samples composed by students, mainly undergraduate ones. The exceptions were soccer players (Furley & Memmert, 2015), architects (Aziz-Zadeh, Liew, & Dandekar, 2012), cellists (in the third experiment by Dreu et al., 2012) and two articles were not clear about their participants (Takeuchi, Taki, Hashizume et al., 2011; Benedek et al., 2014). The studies had participants with an average age between 18.5 and 24.14 years. All studies included participants of both genders, except for those involving soccer players.

Types of intervention and comparison

In the Material section of Tables 1 and 2, due to the chronological organization, in ascending order of publications, there was a transition for the comparison of the results from electroencephalograph (Lavric, Forstmeier, & Rippon, 2000; Razumnikova, 2007) to magnetic resonance imaging combined with tests and tasks (Takeuchi, Taki, Hashizume et al., 2011; Takeuchi, Taki, Sassa et al., 2011; Aziz-Zadeh, Liew, & Dandekar, 2012; Abraham, Thybusch et al., 2014) and, more recently, for the results obtained through cognitive tests (Dreu et al., 2012; Roskes et al., 2012; Lin & Lien, 2013; Lee & Therriault, 2013; Benedek et al., 2014; Yeh et al., 2015; Furley & Memmert, 2015, Tan et al., 2015; Hao et al., 2015).

The techniques to measure brain functioning were: event-related potentials – ERP (Lavric, Forstmeier, & Rippon, 2000), electroencephalography – EEG (Lavric, Forstmeier, & Rippon, 2000; Razumnikova, 2007), functional magnetic resonance imaging – fMRI (Takeuchi, Taki, Hashizume et al., 2011; Aziz-Zadeh, Liew, & Dandekar, 2012) and magnetic resonance imaging – MRI (Takeuchi, Taki, Sassa et al., 2011; Abraham, Thybusch et al., 2014).

As for the instruments used to evaluate creativity, 13 articles evaluated creative ideas, i.e, tests and activities aimed at measuring creative thinking, convergent and divergent thinking, fluency, flexibility and/or originality of the responses generated by the participants. Three articles – experiment 3 by Dreu et al. (2012), experiment 2b by Lin & Lien (2013) and a study by Yeh et al. (2015) – in addition to evaluating creative ideas, they also associated the results of the behaviors of the participants with their creativity in solving concrete problems, such as elaborating the continuity of a piece of music, solving mathematical problems using matchsticks, and making decisions in computer game.

Regarding WM tasks, most of the researches presented computerized tasks to the participants, with the exception of Lavric, Forstmeier and Rippon (2000) – which combined automation and paper and pencil responses –, and the following experiments by Lin & Lien (2013): experiment 1 with verbalization of the answers through numerical sequence count, experiment 2a through rhythmic reading of numerical sequence presented and experiment 2b with computerized task of memorizing items presented in computer screen and verbalization of responses to presented equations. As for the modality, two studies (Razumnikova, 2007; Takeuchi, Taki, Sassa et al., 2011) used verbal tasks of WM and eight used visuospatial WM tasks (Lavric, Forstmeier, & Rippon, 2000; Takeuchi, Taki, Hashizume et al., 2011; Aziz-Zadeh, Liew, & Dandekar, 2012; Lee & Therriault, 2013; Benedek et al., 2014; Yeh et al., 2015; Furley & Memmert, 2015; Tan et al., 2015). The articles of Dreu et al. (2012), Roskes et al. (2012), Lin and Lien (2013), Abraham, Thybusch et al. (2014) and Hao et al. (2015) used WM tasks of both modalities, verbal and visuospatial.

Still with regard to the use of WM tasks, the following studies used span task only: Dreu et al. (2012), Roskes et al. (2012), Lin & Lien (2013), Yeh et al. (2015), Furley & Memmert (2015), Hao et al. (2015) and Tan et al. (2015) and two of them presented only update tasks, Abraham, Thybusch et al. (2014) and Benedek et al. (2014), the last one used 2-back. Both articles by Takeuchi, Taki, Hashizume et al. (2011) and Takeuchi, Taki, Sassa et al. (2011) required the participants to perform complex span task, that is, memorizing progressive sequences in reverse order and an updating task, and Lee and Therriault (2013) required performance on simple span and complex span, which demands serial order.

Characterization of the scientific findings of the scientific review studies

As for the methods used by the studies to analyze the relationship between variables, they can be grouped into the following categories:

1) Analysis of brain activity by: comparison of the cognitive process through the component P300 of ERP during the accomplishment of WM and creative performance tasks (Lavric, Forstmeier, & Rippon, 2000); comparison of electrophysiological parameters regarding topographic variations in three conditions: during the resolution of tests of WM, creative performance or resting condition (Razumnikova, 2007), cognitive comparison of the performance of participants through magnetic resonance obtained during the accomplishment of the tasks of divergent thinking and WM (Takeuchi, Taki, Hashizume et al., 2011); gender cognitive comparison of brain activity obtained by MRI (Abraham, Thybusch et al., 2014) and cognitive comparison of the capacity of creation and mental rotation of geometric figures presented in the tasks of *Creative visual task* and *Control mental rotation task* and analyzed by fMRI (Aziz-Zadeh, Liew, & Dandekar, 2012).

2) Manipulation of WM load by: cognitive comparison of the results obtained by the participants under high and low cognitive WM load in the resolution of tasks of creative insight in the experiments 1 and 2 of Dreu et al. (2012); comparison of the results of manipulation of the load on the creativity of generated ideas and responses to the OSPAN test in the fourth experiment of Dreu et al. (2012); comparison of the degree of creativity of the responses of the participants through 4 categories created by the authors of the groups with and without manipulation of load in the first experiment of Lin & Lien (2013), and cognitive comparison obtained through manipulation of WM load and generation of creative hypotheses in the experiments 2a and 2b of the same authors.

3) Manipulation of motivation and functionality: Roskes et al. (2012) compared the originality of the words created by controlling the functionality of the task in experiment 1; analyzed the variation of the effects of the manipulation of the instruccion presented to the participants in relation to the functionality of the word puzzle tasks in experiments 2a and 2b; compared the relationship between motivation and creative performance also through the resolution of word puzzles in experiment 3, and analyzed the manipulation of cognitive load and functionality of the task in the resolution of creative insight problems in experiment 4.

4) Association of the results obtained through WM and creativity tests: cognitive comparison obtained by correlation between the variables obtained in the tests of intelligence, WM, associative fluency, convergent thinking and divergent thinking (Lee & Therriault, 2013); comparison of the relationships between executive functions, fluid intelligence and creativity between men and women (Benedek et al., 2014); comparison of the results obtained in the tests that evaluated emotion, as well as WM and creativity through the resolution of tasks involving problem situations and games by the two groups of participants who received different concentrations of cortisol (Yeh et al., 2005); cognitive comparison through the correlation between the data obtained in the two tests, *Automated operation span score* and task for creativity of offensive soccer (Furley & Memmert, 2015) and relationship between the role of "mind wandering" in solving problems of insight, OSPAN, self-assessment questionnaire of creativity and motivation and *Daydreaming Frequency* scale (Tan et al., 2015).

5) Evaluation of 'working memory capacity' (WMC) associated with creative performance: evaluation of the creative level of the piece generated from the audio suggestion presented to the participants, relating it to their ability to memorize combinations of 2 or 5 digits in the third experiment by Dreu et al. (2012) and comparison of *Reading Span Task* and creativity data,

represented by the problems of fluency and originality, in the AUT test under verbalization and writing conditions (Hao et al., 2015).

6) Prospective studies: comparison between the results obtained before and after intervention (mental calculus training program to solve the task of arithmetic) and the tests of divergent thinking of the training and control group, contrasted by neuroimaging (Takeuchi, Taki, Sassa et al., 2011) .

As for the neural substrate, it is noticed that different brain areas were activated during the accomplishment of measurements of creativity or WM, as shown in table 1. In the task of creativity of Razumnikova (2007) – RAT –, the activation was more pronounced in the left hemisphere and in the prefrontal cortex. Similarly, the creative task of the article of Aziz-Zadeh, Liew, & Dandekar (2012) – *Creative visual task* – activated regions of the left hemisphere, including the superior frontal gyrus, the inferior frontal gyrus and the medial prefrontal cortex, but there was activation of the posterior parietal cortex as well. On the other hand, the task of monitoring – *Control mental rotation task* – activated the posterior central gyrus, the right posterior parietal cortex, in addition to regions intrinsic to visual processing. Abraham, Thybusch et al. (2014) compared the difference in brain activity between the sexes, and found out that for divergent thinking tasks and *n-back*, men had greater activation in the inferior frontal gyrus, lateral orbitofrontal cortex, and the posterior/inferior half of the temporal gyrus while women presented higher activity in the frontal lobe (Abraham, Thybusch et al., 2014).

Regarding experimental design, 11 studies were cross-sectional quantitative (Razumnikova, 2007; Takeuchi, Taki, Hashizume et al., 2011; Aziz-Zadeh, Liew, & Dandekar, 2012; Dreu et al., 2012; Lee & Therriault, 2013; Lin & Lien, 2013; Abraham, Thybusch et al., 2014; Benedek et al., 2014; Yeh et al., 2015; Hao et al., 2015; Zou et al., 2015), 3 were case-control studies (Lavric, Forstmeier, & Rippon, 2000; Yeh et al., 2015 and experiment one of Lin & Lien, 2013), 1 article was quantitative with random distribution (Roskes et al., 2012) and 1 was experimental with control group and placebo (Takeuchi, Taki, Sassa et al. , 2011).

Through the connection between the descriptors “working memory” and “creativity”, it was tried to establish relationships between the 15 articles selected for this research in order to answer the selected guiding questions. In 13 of the 15 articles, there was an association between the constructs, however, this association could be positive (Lavric, Forstmeier, & Rippon, 2000; Razumnikova, 2007; Takeuchi, Taki, Hashizume et al., 2011; Dreu et al., 2012; Aziz-Zadeh, Liew, & Dandekar, 2012; Roskes et al., 2012; Lee & Therriault, 2013; Abraham, Thybusch et al., 2014; Benedek et al., 2014; Yeh et al., 2015; and experiments 2a and 2b of Lin, & Lien, 2013; Hao et al., 2015) or negative (Takeuchi, Taki, Sassa et al., 2011; experiment 1 of Lin & Lien, 2013). It is important to highlight that some studies showed the influence of individuals WMC on creativity, especially in convergent thinking tasks to the detriment of divergent thinking tasks. As seen on the study of Lin and Lien (2013), there was a positive relation between tasks of creative insight and WM (convergent thinking), but not between WM and the result of TTCT, which evaluates divergent thinking, same result obtained in experiment 3 by Dreu et al. (2012) and by Yeh et al. (2015). Only two of the studies did not show any association between the constructs (Furley & Memmert, 2015; Zou et al., 2015). Underlying the association between both constructs are the inhibitory processes, the neural substrate, functionality and the motivation of the individual. These factors will be referred to below.

Characterization of the cognitive processes involved in the studies of the systematic review

Inhibitory processes: in the paper by Yeh et al. (2015), a greater creativity in the participants was associated with their higher WMC, same result presented by Hao et al. (2015) for participants in the writing condition, who did not need to memorize their answers as the participants in the oral condition. In Benedek et al. (2014), the effective updating process facilitated the search and manipulation of a greater number of concepts necessary to perform creative tasks. Therefore, these studies suggest that both WM processes, update and serial order, influence the creativity development by keeping a new information in a state of full activation and discriminating relevant and irrelevant information (Yeh et al.,

2015). Takeuchi, Taki, Hashizume et al. (2011) also demonstrated that both constructs depend on the same neural substrate, since both WM and creativity tasks activated the precuneus.

Analytical Thinking: the article of Lee and Therriault (2013) found a positive correlation between RAT performance, which evaluates the creative potential, and RAPM, which evaluates intelligence, as well as in RAT results and WM tasks. This suggests that intelligence contributes to creative thinking as it allows activating and retrieving a large amount of ideas from memory and identifying the correct answer to ambiguous solution problems (Lee & Therriault, 2013). Still on the reasoning, Lavric, Forstmeier and Rippon (2000) studied the relationship between WM and creative processes, as well as between WM and analytical processes, and concluded that such processes occur by different neural pathways, since they differ in the amount of thinking required in WM tasks. According to Lavric, Forstmeier and Rippon (2000), the task of creative insight chosen did not provide as much planning and strategies as the analytical task.

Attentional Processes: in study 2 of Dreu et al. (2012) there was a positive relationship between the residence time of the creative task and WM (evaluated through RAT). It was also observed that the participants with high WM presented higher performance in problems of creative resolution. In study 4 of Dreu et al. (2012) it was found that WM was also related to tasks of creative ideas (*Brainstorm task*) regarding persistence (sustained attention) in the task. In studies 2a and 2b of Lin and Lien (2013), creative insight problems correlated with WMC, but the correlation did not reach significance between WM and divergent thinking, even though some participants with low WMC achieved very good performance in the divergent thinking test.

WM overload: the following studies related the manipulation of WM load with creative performance. In experiment 4 of Roskes et al. (2012) it was found that participants in low-load condition (memorization of two-digit sequences) were able to solve more creative insight problems (RAT) than participants in high load condition (memorization of five-digit sequences). Dreu et al. (2012) also observed, in experiment 1, that the low cognitive load of WM allowed a better performance in the task of creative insight, using the same procedure as the previously mentioned study.

Functionality and motivation: Roskes, Dreu, and Nijstad (2012) found that the participants put more efforts to accomplish the first task (Brainstorm and word puzzles) when its creativity goal would be useful in resolving the second task (experiment 1). Besides, the performance was relatively more difficult for the group who was told to avoid making mistakes (experiments 2a and 2b). The difficulty of the creative performance was greater for the participants without motivation in the task than for the participants with motivation measured by index of originality (experiment 3). In study 4, more creative insight problems were solved when the task was considered functional. Therefore, it is advisable to consider the role of motivation as a determinant of creative ability.

Negative association between WM and creativity: two studies obtained a negative relationship between tasks of WM and creativity. Takeuchi, Taki, Sassa et al. (2011) pointed out that the improvement in the cognitive performance related to tasks such as *letter span task* and complex arithmetic tasks occurred concomitantly with the reduction in the performance of the task of creativity. In other words, the training promoted an increase in the selective attention system of the group that started to allocate more effort to the first task to the detriment of the second one. In the experiment 1 of Lin and Lien (2013), it was observed that the increase of WM load decreased the generation of creative hypotheses.

WM and nature of the tasks of creativity: two studies did not find an association between tasks of WM and creativity: Tan et al. (2015) obtained two groups with different results in relation to creativity, measured by the participants themselves according to their creative insights and related to periods of mind wandering, resulting in one group pointing to greater creativity than the other; however, the groups did not present differences in relation to WM scores. The study of Furley and Memmert (2015) used

specific tasks of soccer by presenting offensive soccer scenes to professional players (Furley & Memmert, 2015). Both the task of creativity that evaluated the convergent thinking in this last study and the one that evaluated the divergent thinking did not correlate with WM (corroborating with the results of studies 2 and 3 of Lin & Lien, 2013 and Lee & Therriault, 2013 for divergent thinking). This result was contrary to Dreu et al. (2012), who observed an association between such constructs through creative task of improvisations in musical pieces performed by cellists (in experiment 3), i.e., individuals with high WMC had their creative performance increased throughout the attempts while the opposite occurred in individuals with low WMC. It should be pointed out that the tasks selected in these last two studies related to art and sport, which involve cognition applied to other contexts, while the other studies contrasted creativity with cognitive tasks more influenced by the school experience (manipulation, letters, numbers, etc.).

Final Considerations

Despite the methodological variability presented among the different studies, the results found suggest an association between working memory and creativity, which are explained by attentional, inhibitory, analytical and motivational processes involved. Only two studies indicated an absence of relationship between these constructs, so it is evident that the effect of WM on creativity is dependent on both the type of task selected and the type of thinking it evaluates.

The limitation of this systematic review is the impossibility of performing a meta-analysis with the data obtained due to the absence of *benchmarks* that can guide instruments that adequately evaluate such constructs. In the other hand, restrict the analysis to the most frequent type of WM or thinking processes would considerably limit the number of articles, as well as would present a partial view of the theme. Therefore, the present study presents the state-of-the-art between working memory and creativity in healthy young adults, as an attempt to contribute to the design of future studies that allow deepening the discussion and verifying if the outcomes indicated in the articles selected for this review continue to be confirmed.

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