BEHAVIORAL AND NEUROIMAGING STUDIES ON MULTITASKING: A LITERATURE REVIEW

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- ABSTRACT: This literature review aims at articulating evidence from behavioral and neuroimaging studies on multitasking, where at least one of the tasks is a linguistic one. Simply put, multitasking is the handling of more than one task at the same time by a single person. Findings from six behavioral and five neuroimaging studies were articulated with the literature to corroborate two hypotheses longstanding in the field, that (1) multitasking results in one task being performed more poorly than when performed alone (PASHLER, 1994; SCHMIDT, 2001), and that (2) multitasking is a matter of synchronizing and utilizing more efficiently the available neural resources (SALVUCCI; TAATGEN, 2011; JUST; BUCHWEITZ, 2014). The selected studies investigate simultaneous listening comprehension and driving; listening comprehension and performing mental rotation tasks; dichotic listening comprehension; reading/attending a lecture and messaging; bilingualism; the role of intelligence and working memory capacity; the effects of training; and choices across generations. Findings from the reviewed studies corroborate the literature and add support that less voxels in a network of brain areas are activated in multitasking than in single tasking. Implications of such findings for education were also discussed in the review. Future studies may light the path by showing the brain mechanisms that allow and limit multitasking, the effects of learning under conditions of distraction as well as how teaching may evolve to keep up and guide the new generations.

- KEYWORDS: Multitasking. Dual tasking. Behavioral studies. fMRI. Literature review.

Introduction

The topic 'multitasking' has increasingly interested a number of researchers over the last twenty years. Just by typing 'multitasking' in the search engine of *Portal de*

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Periódicos CAPES¹, it was possible to reach the number of 5,610 studies (on August 16ᵗʰ, 2015). The term 'multitasking' has two different uses: (1) "the simultaneous execution of more than one program or task by a single computer processor"; and (2) "the handling of more than one task at the same time by a single person" (MULTITASKING, 2015). As the focus of this paper is on the second definition proposed by Oxford dictionaries, the articles related to computing were discarded. From the initial 5,610 articles, 1,375 remained for the period 1995-2015, and 1,085 for the period 2005-2015. The majority of the articles published in the last twenty years are written in English (1,349) and published in respected journals such as *Computers in Human Behavior* (40), *Plos ONE* (22), *Computers & Education* (15), *Experimental Brain Research* (9), *Neuropsychologia* (9), *Journal of Experimental Psychology: Human Perception and Performance* (8), to mention but a few.

Modern life requires multitaskers. Multiple events occur simultaneously and individuals need to deal with them immediately and concurrently. As technology develops, individuals have at their disposal new communication devices, multiplying the number of available information that we have to process. According to Ophir, Nass and Wagner (2009), we live in a saturated media environment in which we consume more than one stream of information at the same time, and perform more than one task at a time. Multitasking may seem so easy that we do not realize we are doing it, such as *talking* while *walking*, *showering*, or *eating a meal*; *mixing ingredients* while *reading a recipe*; *listening to a lecture* and *taking notes*; among many other tasks. At other times, multitasking may become difficult, excruciating or even impossible, as when people are trying to *drive* while *scanning a navigation device*; when *trying to read an academic article* while *listening to other people talking* about an interesting subject; or when *performing a working memory capacity task* in which you have to process information while *storing other kinds of information*. Real life situations require multitasking abilities. Practicing is one of the most obvious ways to ease the burden of multitasking. For instance, when beginning to learn a foreign language, everything seems so hard; it is difficult to pronounce the words, put them into grammatically accurate sentences; but soon each subprocess becomes easier, some processes become automatized and the individual can produce and understand coherent speech with fluency (SKEHAN, 1998). This process takes time and effort, but it is an example of the amount of practice required to achieve expertise in any domain. According to Schmidt (2001), automatic processes require little or no attention while controlled processes require attention as well as interfere with other processes that also require it.

Multitasking is a fundamental skill that we perform on a daily basis. Even though we perform it so well, we have difficulty explaining and understanding such a feat. Additionally, the increase in the amount of available information, which is

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¹ Is a website created by CAPES and the Brazilian government where Brazilian scholars and students, from different areas of expertise, can find a broad range of scientific articles published worldwide. Available in: <http://www.periodicos.capes.gov.br/>. Access in: 16 Aug. 2015.

a consequence of our living in such a high-tech world, brings to light the issue of whether and how our brains cope up with the task of processing more than one stream of information at a time. With the advent of neuroimaging tools that enable us to see the healthy brain at work, to unveil the brain mechanisms that support and limit our multitasking ability is a scientific challenge (JUST; BUCHWEITZ, 2014). An even greater challenge is to apply such findings to improve learning and performance at school, work and leisure contexts.

In what follows, groundbreaking behavioral and neuroimaging studies of multitasking, where at least one of the tasks involves language, are reviewed briefly with focus on the patterns that emerge from the data. The main objective of the present article is to articulate evidence from such studies to corroborate the hypotheses that (1) multitasking normally results in one task being performed more poorly than when performed alone (PASHLER, 1994; SCHMIDT, 2001); and that (2) multitasking is not a matter of recruiting more brain areas; it is, instead, a matter of synchronizing and utilizing more efficiently the available neural resources (SALVUCCI; TAATGEN, 2011; JUST; BUCHWEITZ, 2014). Within this main objective, we seek to understand how multitasking takes place in the brain, how our brains cope up with the task of processing various tasks, various streams of information at a time. In addition, we aimed at reviewing studies that investigated how learning and performance take place under conditions of distraction. To reach such goals, six behavioral and five neuroimaging studies were selected. They are thought to represent the major areas explored by studies about multitasking where at least one of tasks involves language.

To accommodate the objectives, the present article is divided into three subsections: (a) behavioral studies of multitasking; (b) neural substrates of multitasking; and (c) final remarks. The content in each subsection is organized thematically, rather than chronologically. In the first subsection, the findings from six behavioral studies are articulated: first, (i) two studies about language comprehension and messaging; (ii) one study about the benefits of bilingualism for multitasking; (iii) one study about language comprehension and driving; (iv) one study about the role intelligence and working memory capacity play in multitasking performance; and (v) last, but not least, one study about multitasking choices across generations. In the second subsection, the results from five neuroimaging studies are articulated: first, (i) one study about multitasking in a brain lesioned sample; (ii) one study about dichotic listening (listening to one voice in one ear and another voice in the other ear); (iii) one study about the impact of listening comprehension on driving performance; (iv) another study about listening comprehension and the simultaneous performance of mental rotation tasks; and (v) last but not least, a study about how the human brain responds to training in multitasking. In the last subsection, the main findings are recapped in the light of the literature and some reflections about education are offered.

Behavioral studies of multitasking

The cognitive literature has suggested that our capacity for processing information is limited (KAHNEMAN, 1973). Due to our capacity limitations, dividing attention among one or more different tasks leads to decrements in performance (PASHLER, 1994). There are many published behavioral studies of multitasking and attention, but due to the objectives and limits of this paper, only six recent studies representative of five thematic areas will be reviewed.

First, let us start by examining existing empirical evidence about whether multitasking in a learning environment affects students' performance. Bowman et al. (2010) investigated the effects of instant messaging while students were reading a textbook. The experimental study design created a situation in which 89 college students read a passage from a textbook online while receiving and answering instant messages. The researchers tracked the time it took them to read the passage, tested their understanding of it, and compared their performance (experimental group) to that of students who were not interrupted by instant messages (control group). The experimental group was divided into two: one in which participants received messages before reading the text and another group in which they received messages while reading. As expected, students took significantly longer to read the passage when they used instant messaging while reading compared to the group that did it before reading and to the group who did not receive or send messages at all. Contrary to what was hypothesized (that multitasking would lead students to superficially process the passage), there were no significant differences in performance on the test for measuring comprehension. Therefore, it can be concluded that students "actually need more time to achieve the same level of performance on an academic task" (BOWMAN et al., 2010, p.931) when they are multitasking. The present review questions some methodological issues found in Bowman et al. (2010) study, such as the instrument used to measure reading comprehension (multiple choice test) and the initial instructions given to the participants (the group that received messages before the passage, for instance, knew that they would not be interrupted afterwards, while the other groups did not receive any related instruction). Despite such issues, the study highlights that students who message while studying may think that they are accomplishing more by multitasking, but in fact, they are taking longer to achieve the same level of performance in a reading/comprehension task.

Within the same theme, Ellis, Daniels and Jauregui (2010) designed a study to empirically explore whether multitasking in the context of a classroom affects the grade performance of 62 undergraduate business students. The participants, students from a university in the U.S., attended a class lecture and subsequently were given a quiz covering the lecture content (they did not know in advance that they would have to perform). The experimental group with 31 students, randomly assigned, was instructed to multitask by sending three messages through their cell phones to the professor during class while 31 different students of the control group were not allowed

to turn their cell phones on and were asked to pay attention to the class. All participants were instructed not to talk to anyone during the lecture to ensure anonymity about the study. Findings show that the experimental group students had lower scores than the control group students. From the sample, 26 were male and 36 were female, and the analyses revealed that gender does not affect performance. Overall, the results are in accordance with the idea that multitasking reduces the ability of the brain to effectively retrieve information. In the authors' own words, "[…] evidence shows that there is a cost associated with multitasking in a learning environment – lower grade performance […]" (ELLIS, DANIELS; JAUREGUI, 2010, p.6). Both studies, Bowman et al. (2010) and Ellis, Daniels and Jauregui (2010), tackle the effects of messaging on academic performance. In classrooms all over the world, teachers encounter students using media for social purposes that distract from academic tasks. Notwithstanding, media technological tools have a great potential to enhance learning, if used appropriately. Therefore, it is relevant to be discussed in the educational field how to help students become media literate, how to help them deal with multitasking.

As we have discussed multitasking in learning environments, it seems pertinent to bring to light the issue of bilingualism. According to Grosjean (2012), bilingualism is a worldwide phenomenon. Some countries support bilingual populations mainly because of the cultural and linguistic diversity of its citizenry. In addition, increased possibilities of moving around the globe have enlarged the number of individuals who have become bilingual. Nevertheless, what does it take to be considered a bilingual? Grosjean (2012, p.4) defines bilinguals as "those who use two or more languages (or dialects) in their everyday lives". They do not form a homogeneous group; they vary along a number of dimensions: age and manner of acquisition, level of proficiency and how much and in what contexts they use their languages. Bilinguals need to control, on a regular basis, which language to choose in a certain context and inhibit interference from the language not in use. Poarch and Bialystok (2015, p.121) postulate that "this process makes all language use by bilinguals a model for linguistic multitasking". They argue that bilingual experience enhances the set of executive function processes that are also essential for multitasking performance. Thus, they hypothesize that bilinguals should be better multitaskers than monolinguals.

In the attempt to provide empirical evidence for such a position, Poarch and Bialystok (2015) recruited 203 children from 8 to 11 years old: 60 were English monolinguals; 44 were being educated in French but used it only in school (partially bilinguals); 60 were fully bilingual; and 39 were trilingual. Among the tasks, participants performed the Peabody picture vocabulary test, the Raven's colored progressive matrices test and a modified flanker task[2]. The study did not involve any measure of task switching

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[2]	In the modified flanker task used by Poarch and Bialystok (2015, p.119), participants were required to "[…] indicate the direction in which a target chevron in the middle of an array of five chevrons was pointing by pressing one of two mouse buttons positioned on either side of the computer." The authors employed four types of trials: (1) baseline trials in which a single chevron was presented in the middle of the screen; (2) neutral trials in which two diamonds surrounded the middle chevron; (3) congruent trials in which "the flanking chevrons pointed in the same direction

or multitasking, but the authors guarantee that the flanker test has the central elements of multitasking: selection, inhibition and response shifting. Results showed that the children from all groups performed similarly in English vocabulary and nonverbal intelligence, accuracy was at ceiling, but bilinguals and trilinguals outperformed monolinguals, i.e., were faster at resolving conflict than monolinguals and partial bilinguals. The researchers explain that both languages in bilinguals are constantly active; they need to direct attention to the target language and avoid interference from the non-target one. Therefore, there is a bilingual advantage in executive function (EF), since the EF system controls attention. In the authors' own words, "[…] the involvement of EF in bilingual language processing makes bilingualism a form of linguistic multitasking […]" (POARCH; BIALYSTOK, 2015, p.113).

Moving slightly away from the educational context, Engonopoulos, Sayeed and Demberg (2012) investigated the effect of linguistic complexity on cognitive load in a dual-task situation: simultaneous driving and language use. The researchers manipulated the driving task difficulty as well as the structural complexity of the linguistic items. A total of 24 participants performed a simulated driving task that varied between 'easy' and 'difficult' driving while listening to sentences in German containing a relative clause. The clause was followed by thematically related filler sentences and participants had to answer yes/no comprehension questions. The stimuli were designed in pairs in a way that the items in each pair are similar with the exception of the form of the auxiliary of the relative clause, which defines whether it is a subject relative clause or an object relative clause. The sentences are locally ambiguous between the object and subject relative clause until reaching the auxiliary. As an example, "*Die Lehrerin, die einige Eltern wegen einer solchen Kleinigkeit angerufen [**haben / hat**]*, *hat nun eine Elternversammlung einberufen*" ("The teacher $_{FEM}$ [who called some parents / whom some parents called] because of such a trivial issue, has now called a parents' meeting") (ENGONOPOULOS, SAYEED; DEMBERG, 2012, p.2250). The researchers also collected physiological data based on two measures: pupillometry and skin conductance response. Results indicate that the language task undoubtedly disturbs performance on the driving task. Additionally, linguistic ambiguity and complexity resulted in higher cognitive load, as measured by the two physiological tests. The authors explain that in the disambiguating region they observed higher steering deviation, indicating that "[…] people are allocating more mental resources to the linguistic task, hence impeding steering performance […]" (ENGONOPOULOS; SAYEED; DEMBERG, 2012, p.2253). This issue of comprehending language and driving will be better discussed in the following subsection with neuroimaging evidence.

Moving to the professional context, Colom et al. (2010) examined the role played by intelligence and working memory capacity (WMC) in multitasking performance.

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as the target"; and (4) incongruent trials in which "the target and flanking chevrons pointed in opposite directions" (POARCH; BIALYSTOK, p.120). This test is widely used in cognitive psychology to assess the ability to suppress responses that are inappropriate in a particular context.

The study was conducted with 302 applicants for admissions to air traffic control training courses. Intelligence was measured by an analytic reasoning test; WMC, by the computation span and dot matrix tasks; and multitasking, by the divided attention and funnel tasks[3]. Researchers found that, although both intelligence and WMC are related to multitasking, WMC is more highly correlated and it is the one that predicts multitasking performance. They explain that the processing and storage components of WMC tests are highly related to the skills required by multitasking. In their own words, "working memory tasks might be used for personnel selection when multitasking requirements are involved" (COLOM et al., 2010, p.550).

Due to the relatively recent technological urge, the last theme of this subsection involves the perception and choices made by individuals from different generations. Carrier et al. (2009) explored the multitasking choices and difficulty ratings in three generations of north-Americans: Baby Boomers[4], born between 1946 and 1964; Generation X, born between 1965 and 1979; and Net Generation, born between 1980 and the present. It is the first study to directly compare the multitasking behavior of older and younger generations. The authors claim that the Net Generation members "grew up with computer-based technology readily available and enmeshed in their school and home environments" (CARRIER et al., 2009, p.483). An online questionnaire about different technology-related tasks was answered by 1319 participants. As expected, more recent generations significantly multitask more than older generations. Surprisingly, newer and older generations agreed on which tasks should be combined for multitasking and which should not. Such finding is "[…] consistent with the idea that all generations share mental limitations affecting which tasks can be combined with other tasks […]" (CARRIER et al., 2009, p.489). As limitations, such results may potentially be due to chronological age rather than generational differences; and the responses to the questionnaire reflect the participants' perceptions of their own multitasking experiences rather than their real multitasking behaviors. By any means, it seems that the limitation in multitasking ability is shared across generations. Adding to the findings of this study, Ophir, Nass and Wagner (2009) compared cognitive control abilities between chronic heavy media multitaskers with those who occasionally multitasked. Their findings suggest that either "heavy media multitaskers are distracted by the multiple streams of media they are consuming", or those who rarely multitask are "more effective at volitionally allocating their attention in the face of distractions" (OPHIR; NASS; WAGNER, 2009, p.15585). They conclude that the increased need for multitasking may be placing new demands on cognitive processing and especially on attention allocation.

These studies have shown that tasks may compete for a common central cognitive processing resource, resulting in a bottleneck. Pashler (1994, p.221) sustains that

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[3] For details, check the original paper.

[4] Baby Boomers were born between 1946 and 1964 in countries such as the United Kingdom, France, the United States of America, Canada or Australia. After World War II, these countries had a sudden increase in the birth rate (U.S. CENSUS BUREAU, 2011).

"when two tasks need the mechanism at the same time, a bottleneck results, and one or both tasks will be delayed or otherwise impaired". We have seen that multitasking is a ubiquitous need in modern life and people believe that they are using time more effectively by performing more than one task at the same time in different contexts. In reality, studies, as the ones reviewed here, have suggested that individuals are being distracted, and such a fact interferes with their ability to perform tasks, to retain and retrieve information/knowledge. Now, let us explore such multitasking issues through the lenses of neuroimaging, a set of techniques that can image the brain, especially the healthy brain, at work.

Neuroimaging studies of multitasking

The neural basis of multitasking has been inspected through lesion studies and more recently through technological tools, such as functional magnetic resonance imaging (fMRI)[5]. Among the many published studies, one lesion study and four neuroimaging studies were chosen to be reviewed here. These studies confirm the long known hypothesis that brain areas do not work in isolation, one at a time; they collaborate extensively to achieve a goal. They corroborate the idea that the human brain is capable of reorganizing itself, put forward by William James in his *Principles of Psychology* (1890). As well, they follow the basic principles from the Parallel Distributed Processing approach proposed by McClelland, Rumelhart and PDP Research Group (1986) that cognitive processes take place in parallel in a distributed network of cortical areas.

According to Just and Buchweitz (2014), to accomplish a task, such as sentence comprehension, different areas are synchronized (PRAT; JUST, 2010), activation levels rise and fall together, indicating that information is being transferred among the areas, what is referred to as coordination of activity. Just and Buchweitz (2014) review six principles articulated by Just and Varma (2007) that are consistent with the majority of fMRI studies, including studies of multitasking: (1) there is not only one area activated in the accomplishment of a task, there is rather *a network of cortical areas*; (2) each area activated has a characteristic processing style; (3) areas are assembled dynamically as task demands increase; (4) activation is synchronized between the participating areas; (5) the more demanding the task, the greater the amount of activation in the area(s) involved; and (6) cognitive centers are tightly integrated with sensory and motor centers; activation rises and falls at the same time.

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[5]   According to Huettel, Song and McCarthy (2009), fMRI is a noninvasive technique based on the same technology of magnetic resonance imaging (MRI). It uses a strong magnetic field and radio waves to create detailed images of the brain. fMRI measures brain activity by detecting changes in blood oxygenation and flow that occur in response to neural activity (when a brain area is active, it consumes more oxygen to meet the increased demand). The technique is used to produce activation maps showing which parts of the brain are involved in a particular cognitive process. Besides being noninvasive, it presents excellent spatial resolution and good temporal resolution. It has become a popular tool for imaging normal brain function and has been providing new insight to the investigation of cognition.

Historically, lesion studies were the only way to study the human brain before the advent of neuroimaging techniques, so let us start by reviewing one. Burgess et al. (2000) investigated 60 patients that had suffered focal brain lesions. These patients performed tasks that tackled retrospective and prospective memory, as well as planning skills. Findings indicate that different stages involved in multitasking are disrupted by lesions to different brain areas. The left posterior cingulate region and extensions to the occipital lobe seem to reflect impairments to retrospective and prospective components of the tasks; the right dorsolateral frontal regions appear to reflect deficits in planning. Damage to such regions leads to decrements in task performance. The study presented a tentative account "to explain how these brain regions might interact together in supporting multitasking" in a brain lesion sample (BURGESS et al., 2000, p.860). Although the investigation of brain lesions presents limitations and results should be interpreted with caution (BOOKHEIMER, 2002; MATLIN, 2004), Burgess et al.'s study (2000) shows that there are particular areas of the brain where injury leads decrements in performance in different stages of multitasking.

With time and technological development, researchers became able to observe and study the healthy brain at work. Let us now reflect upon three studies that deal with language (listening) comprehension and an additional task. Buchweitz et al. (2012) investigated, using fMRI, how twelve college-level participants dealt with the task of listening to a male voice speak in one ear and a female voice in the other ear (dichotic listening), and understanding what each one of them was speaking. The researchers compared this situation to the single task (listening and understanding a single speaker) and found that the same set of areas was involved in both conditions. In the multitask situation, they observed an increase in activation in Broca's and Wernicke's areas[6] and also an increase in the synchronization between these areas. In the single task, it seems that Broca's and Wernicke's areas are not completely synchronized, as revealed by the fact that Broca's activation occurs later (by about 1.6-2.0 seconds) than Wernicke's. In the dual task, peak activations of the two areas differ by only 0.7 sec, meaning that they synchronize during multitasking, leading to the maintenance of good performance in both tasks. Figure 1 presents the areas activated in each situation. As regards the probe questions designed to check comprehension, results revealed that response times were slower in the dual-task condition, as expected.

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[6] Broca's and Wernicke's areas are traditionally implicated in language processing (PRICE, 2010). They were named after the physicians that identified them in the 1800's. They observed the behavior of patients with brain lesions and studied their postmortem brains. Broca's area is a region in the frontal lobe, more specifically in the inferior frontal gyrus, associated with language production. In turn, Wernicke's area is a region in the superior temporal gyrus, implicated in language comprehension. According to Bookheimer (2002), the lesion deficit-approach has led to a large-module philosophy, that the language system is composed of only these two domain regions.

Figure 1 – Contrasting between multitasking situations, single task and rest.
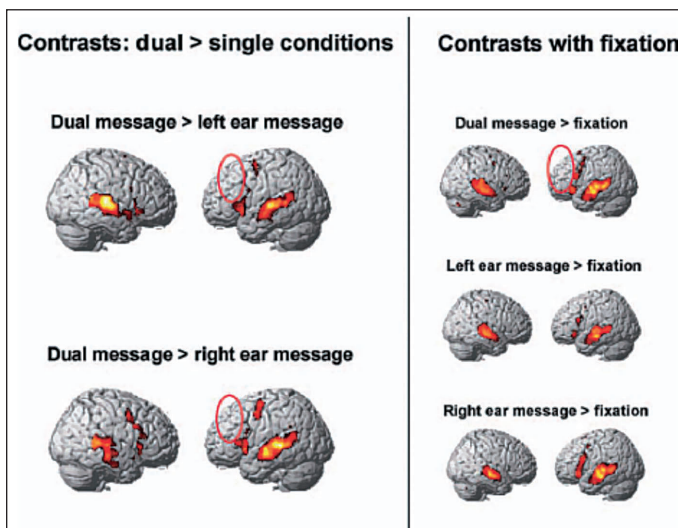
Buchweitz et al. (2012) also observed the effects of WMC in multitasking. Lower WMC participants displayed larger time shifts maybe because they were not as able as higher capacity individuals to keep the results of two areas activated together when there were so many results to keep active. Unsuccessful participants were the ones who could not synchronize both tasks. The study shows that "[…] multitasking may be more than just a matter of doing more brain work. It may also be a matter of doing the work differently in adaptation to the doubled workload […]" (JUST; BUCHWEITZ, 2014, p.8).

As mentioned previously, behavioral studies have stated that our capacity for processing information is limited and brain imaging studies have added that there is a limit on the amount of activation that can be recruited for a given task at a given time. Just and Buchweitz (2014, p.6) explain that

> […] if performing one task alone activates some volume of the brain, say x voxels, and another task alone activates y voxels of the brain, then perfect additivity of the two tasks might be expected to activate x+y voxels. But that is not what happens. Typically performing both tasks simultaneously activates substantially less than x+y voxels.

In multitasking, "[…] the brain activity involved in performing two tasks at the same time is not a simple union of the activity underlying each of the two component tasks […]" (JUST; BUCHWEITZ, 2014, p.4). Prat, Mason and Just (2011) suggest that this 'doing more with less' reflects neural efficiency. Additionally, our brains are

capable of adapting themselves to the demands of the tasks involved, a concept known as neural adaptability (PRAT; JUST, 2010). As well, different networks involved in accomplishing tasks are able to become synchronized; it means that the activation of networks of different regions rise and fall in tandem, indicating that such regions are collaborating and connected functionally (PRAT; JUST, 2010).

Just, Keller and Cynkar (2008) used fMRI to explore the impact of concurrent listening comprehension on the brain activity associated with a simulated driving task. The dual task situation resulted in a significant decline in driving accuracy. It also revealed a decrease of about 37% of activation in the parietal lobe, an area traditionally associated with spatial processing. The findings, as shown in Figure 2, "[…] clearly establish the striking result that the addition of a sentence listening task decreases the brain activation associated with performing a driving task, despite the fact that the two tasks draw on largely non-overlapping cortical areas […]" (JUST; KELLER; CYNKAR, 2008, p.75).

Figure 2 – The impact of simultaneous listening in brain activity associated with a simulated direction task.
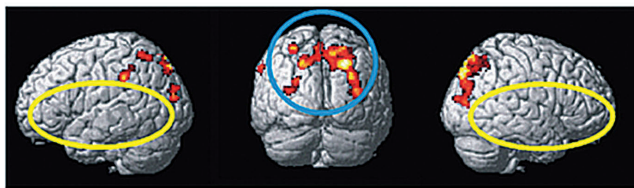
Source: Reprinted with permission from the authors Just, Keller and Cynkar (2008, p.73).

Results confirm the hypothesis that understanding sentences disrupts driving performance by distracting attention[7] from the driving task. Such finding corroborates Engonopoulos, Sayeed and Demberg's findings (2012) from their behavioral study (reviewed above). This distraction effect may be interpreted as reflecting the limit of resources/attention that can be distributed across both tasks. In the authors' words

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[7]   For a review on attention see Bailer (2011, p.16-21).

(JUST; KELLER; CYNKAR, 2008, p.76), "[…] this capacity limit might be thought of as a biological constraint that limits the amount of systematic neural activity that can be distributed across parts of the cortex […]". In countries such as Brazil and the USA, legislation prohibits the use of cell phones while driving. If the individual is holding the phone in hand (handheld use), s/he receives a fine; but if the individual has the phone inside the car in a stationary place (hands-free use), it is not considered as an infraction. Concerning this issue, Salvucci and Taatgen (2011, p.108) ponder that "[…] there are no significant differences between handheld and hands-free phone use, since the visual and cognitive requirements are effectively identical […]", thus, our cognition is impaired both by handheld and hands-free phone use while driving.

It is essential to highlight that automatic processes require little or no attention while controlled processes require attention as well as interfere with other processes that also require it (SCHMIDT, 2001). Neuroimaging studies have updated this definition, by claiming that "[…] a skill or behavior becomes automatic when there is a transition from goal-directed behavior controlled by a frontal-parietal executive system to a state in which the frontal strategic control drops away […]" (JUST; BUCHWEITZ, 2014, p.9). Tasks can become automatic, meaning that they consume fewer resources, as a result of extensive practice. In the case of driving, while learning how to drive, our attentional resources are totally consumed by the task of driving and as we become more proficient in the task, we might feel capable of answering the cell phone or following a navigation device. The act of shifting gears or using the clutch may become automatic, but as highlighted by Salvucci and Taatgen (2011), "[…] it imposes a heavy procedural workload on cognition that, especially in difficult driving conditions, leaves little processing capacity available for other tasks […]" (SALVUCCI; TAATGEN, 2011, p.107). Therefore, it seems clear from the evidence that driving and using the phone at the same time is not a good combination.

While Buchweitz et al.'s study (2012) required the comprehension of simultaneous spoken sentences and Just, Keller and Cynkar's study (2008) explored the effects of listening comprehension on a driving task, Just et al. (2001, p.417) measured "[…] cortical activation during the concurrent performance of two high-level cognitive tasks that involve different sensory modalities and activate largely nonoverlapping areas of sensory and association cortex […]". The tasks involved a mental rotation task of visually depicted 3D objects and a listening comprehension activity and it is assumed that independent brain networks underpin them. Results reveal that performing the two tasks concurrently draws mental resources away from the language processing and mental rotation regions, reflecting decrements in performance. As reported by Buchweitz et al. (2012) and by Just et al. (2001), the activation of both networks involved in the two tasks decreased from single to dual tasking.

Behavioral studies describe decrements in performance as a result of interference. For instance, research on bilingualism has found that, compared to monolinguals, bilinguals are better able to direct their attention to task-relevant information and further

maintain their attention despite adverse interference (YANG et al., 2005). According to Just and Buchweitz (2014, p.13), "[…] interference remains a label for a phenomenon without much explanation of the underlying mechanism […]". These authors argue that brain-imaging studies are able to identify the brain areas involved in multitasking, its effects like performance degradation, and indicate, at times, the psychological processes involved. Other scholars such as Salvucci and Taatgen (2011) perceive interference from a different perspective. They reason that different individuals have very different abilities in particular tasks and that such difference comes from differences in people's skills and abilities in the individual task domain. A theory called *Threaded cognition* postulates that "[…] carrying out concurrent novel tasks is very hard because of declarative interference, but much easier as expertise in one or both tasks is acquired […]" (SALVUCCI; TAATGEN, 2011, p.257). The authors explain that novices rely more on declarative memory processes to execute a task. As experts do not rely so much on memory retrieval, they are faster at deciding what they have to do and make fewer errors. Such "reduced reliance on declarative memory makes it easier for them to do tasks in parallel" (SALVUCCI; TAATGEN, 2011, p.171).

Yet, tasks may compete for a common central cognitive processing resource, resulting in a bottleneck. As aforementioned, in a multitasking situation where the same mechanism is needed, one or both tasks may take more time to be accomplished and/or performance may be impaired (PASHLER, 1994). Brain imaging studies have been interested in finding out whether the decrements in performance reflect a limitation in the ability to perform concurrent tasks or in the engagement of executive functions and strategies to enhance performance. According to Just and Buchweitz (2014), brain imaging confirms the role of the executive network and strategic control for the processing of concurrent tasks.

Executive functions are central for situations that require switching attention between tasks, since these functions help organize goal-directed actions. The executive network involves the prefrontal cortex (PFC) and is associated with directing attention and maintaining information, thus working memory (OSAKA; OSAKA, 2007). It is well known that executive functioning can be impaired by brain injury, age, and neurodegenerative diseases. According to Just et al. (1996), brain resources are measured in two ways: the volume of neural tissue that is activated above resting state and the mean activation of a volume. Studies of higher-order cognition have found that high-functioning individuals utilize fewer resources, displaying more focal activation (PRAT, MASON; JUST, 2011), what is known as neural efficiency (doing more with less). It has been reported as a functional indicator of individual differences among more-skilled and less-skilled readers (PRAT; JUST, 2010). In the area of multitasking, few studies have investigated the impact of individual differences. For instance, Buchweitz et al. (2012) did not find WMC to correlate with dual-tasking ability, possibly because the task was either too easy or too difficult for the participants. The researchers only recruited individuals who achieved an accuracy

rate of at least 75% in the dual task practice session before scanning, what represents around 35% of the initial sample of screened participants. In the authors' own words, "[…] the successful participants showed a change in the temporal organization of their neural processing, a shift in the timing relation among nodes in the language network, achieving higher functional connectivity in the dual task condition […]" (BUCHWEITZ et al., 2012, p.1881).

Higher performers are capable of maintaining consistent levels of performance even when task difficulty increases, without consuming all cognitive resources. As stated by Just and Buchweitz (2014, p.10), "[…] high levels of performance in multitasking may be underpinned by neural efficiency; the use of fewer resources in areas of the prefrontal cortex, in turn, may be associated with the ability to automate task-specific dual-tasking processes." In turn, lower performers experience decrements in performance, since they select strategies of low efficiency, thus, consuming more brain resources. Cole et al. (2013) suggest the existence of fronto-parietal flexible hubs to explain how the brain implements the ability to adaptively control its own behavior. Braun et al. (2015, p.1) complement this view by claiming that "[...] individuals with greater network reconfiguration in frontal cortices show enhanced memory performance, and score higher on neuropsychological tests challenging cognitive flexibility."

Moving back to the educational context as discussed in the previous subsection about behavioral studies, such studies are difficult to be implemented inside a scanner due to its limitations. For instance, participants ought to remain still while being fMRI scanned, that is precisely why it is so difficult to study language production with fMRI. Therefore, studies are designed taking into consideration the limitations of the instrument. Dux et al. (2009) was the closest study to the educational context we found. Dux et al. (2009) examined how seven participants responded to training in multitasking. Despite not including any linguistic task, only distinct sensory-motor tasks, the study is relevant to mention in this review since it tackles the issue of training in multitasking performance. Participants received training on a daily basis during a period of two weeks. They were fMRI scanned before training, at the midpoint of training and after training had been concluded. According to the authors, in the literature there are two accounts of the training effects. The first posits that training results in a reorganization of the brain areas that support task performance while the second sustains that training improves the efficiency of the preexisting neural networks. As findings, reaction times were reduced with training and no additional areas were recruited in multitasking. The researchers concluded that training led to an increase in the speed of information processing in the prefrontal cortex, thus, allowing multiple tasks to be processed quickly. Training leads to more efficient multitasking, reducing the multitasking costs by decreasing the dependence on executive control. Efficient multitasking, rather than recruiting additional brain regions, is "[...] associated with better synchronization or coordination between task-related areas and more efficient use of neural resources [...]" (JUST; BUCHWEITZ, 2014, p.11).

As regards biology, the human brain did not change over thousands of years, but its cognitive capabilities keep expanding. Dehaene (2009) argues that cerebral plasticity allows our neuronal circuits to operationalize cultural and educational inventions such as reading and writing. His theory posits that the neural networks of the human brain are *recycled for reading* written language, since learning to read adapts and connects the occipital and temporal brain regions already present in the child, concentrating reading processes in the left-occipitotemporal letterbox area. In Dehaene's own words (2009, p.302), "only a stroke of good fortune allowed us to read". As our brains adapted themselves to read, they may be adapting themselves to multitasking.

Final remarks and future directions

Bearing in mind that "a review is limited to the reviewer's own understanding of the topic and how the conclusions of each paper fit together" (PRICE, 2010, p.62), this paper aimed at articulating evidence from behavioral and neuroimaging studies on multitasking where at least one of the tasks involved language to corroborate two hypotheses longstanding in the field, that multitasking results in one task being performed more poorly than when performed alone (PASHLER, 1994; SCHMIDT, 2001), and that multitasking is a matter of synchronizing and utilizing more efficiently the available neural resources (SALVUCCI; TAATGEN, 2011; JUST; BUCHWEITZ, 2014). The paper sought to provide an understanding of how our brains cope up with the task of processing various tasks, various streams of information at a time. Additionally, we sought to articulate findings from studies that investigated how learning and performance take place under conditions of distraction. We selected six behavioral and five neuroimaging studies thought to represent the major areas explored by studies about multitasking where at least one of tasks involves language.

As reviewed here, dual-tasking/multitasking may be defined as a complex cognitive process that "usually results in at least one of the concurrent tasks being performed more poorly than when it is performed alone" (JUST; BUCHWEITZ, 2014, p.1). Multitasking demands more mental resources than single tasking, since the former requires complex cognitive processes to occur simultaneously while sharing a common infrastructure. Some scholars have proposed that it is not a matter of recruiting more brain areas; it is, instead, a matter of neural efficiency and neural synchronization. We have to keep in mind that many variables influence the studies such as the profile of the participants, the tasks used to examine the effects of multitasking, the level of automaticity participants exhibit in the tasks proposed, the procedures and instructions used, the results and the interpretation of findings. Overall, findings from the studies reviewed here agree with the literature that a network of brain areas is activated in the accomplishment of tasks and that activation in such areas is synchronized. In addition, the more demanding the task, the greater the amount of activation in the areas involved,

the greater the cognitive resource consumption. Such facts are reflected, for instance, in the legislation of countries like Brazil, that do not permit handheld cell phone use while driving.

With technology, new devices and new forms of communication are emerging, leading our brains to adapt themselves to the new requirements of living in this society. For better or worse, multitasking skills are required in such a high technology world. As far as we know, Carrier et al.'s study (2009) is the only one to compare multitasking across generations. They found that newer generations seem to be more used to multitasking although they recognize they cannot combine demanding tasks.

Although the ubiquity of multitasking is clear, learning and performance under conditions of distraction is a growing concern. Educators ought to be aware of the risks posed by new technologies. Bowman et al. (2010, p.930) recommend that "[...] the benefits must be weighed against the tendency students have to use media for irrelevant, social purposes that may distract significantly from the target academic tasks." In addition, educators should understand the challenges of multitask and have time available to talk to students about the uses and limitations of multitasking as part of school information as well as help students become media literate. According to Ellis, Daniels and Jauregui (2010), if used appropriately, media technological tools are powerful devices with potential to enhance learning; but if used inappropriately, they can bring harmful outcomes to learning.

Future studies may clarify these issues, as well as how teaching may evolve to keep up and guide the digital native generation, how to teach teens and adults to deal with this increasingly multistream world. Just and Buchweitz (2014, p.14) advocate that "[...] the central scientific challenge is to further understand the brain mechanisms that both enable and constrain multitasking and to use this understanding to enhance learning and performance in educational, workplace, and recreational contexts."

Acknowledgements

- *RESUMO: Esta revisão de literatura objetiva articular evidências de estudos comportamentais e de neuroimagem que têm sido conduzidos sobre multitarefa, nos quais pelo menos uma das tarefas envolve linguagem. De forma bem simples, ser multitarefa é lidar com mais de uma tarefa ao mesmo tempo. Achados de seis estudos comportamentais e de cinco estudos de neuroimagem foram articulados com a literatura para corroborar duas hipóteses consagradas*

na área, de que (1) ser multitarefa resulta em demonstrar desempenho inferior em uma das tarefas (PASHLER, 1994; SCHMIDT, 2001), e de que (2) ser multitarefa envolve sincronizar e utilizar de forma mais eficiente os recursos neuronais disponíveis (SALVUCCI; TAATGEN, 2011; JUST; BUCHWEITZ, 2014). Os estudos selecionados investigam compreensão auditiva e direção; compreensão auditiva e desempenho de tarefas de rotação mental; escuta dicótica e compreensão; leitura/participação em palestra e envio de mensagens; bilinguismo; o papel da inteligência e da capacidade de memória de trabalho; os efeitos do treinamento; e as escolhas multitarefa em gerações diferentes. Os resultados advindos dos estudos revisados corroboram a literatura e mostram que menos 'voxels' são ativados em uma rede de áreas cerebrais em situação multitarefa do que ao desempenhar as tarefas individualmente. Implicações dos achados para a educação também são tratados na revisão. Estudos futuros podem contribuir mostrando os mecanismos cerebrais que permitem e limitam os indivíduos em ser multitarefa, os efeitos do aprendizado em condições de distração bem como a maneira como o ensino pode evoluir para guiar as novas gerações.

- *PALAVRAS-CHAVE: Multitarefa. Dupla tarefa. Estudos comportamentais. fMRI. Revisão de literatura.*

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