Air Traffic Controllers and Executive Brain Function

Ângela Maria de Freitas; Mirna Wetters Portuguez; Thaís Russomano; Jaderson Costa da Costa

BACKGROUND: This study evaluated the executive functions of air traffic controllers (ATCs) in relation to demographic and occupational characteristics such as length of service, technical qualifications, and work shifts.

METHODS: This was a cross-sectional study based on a convenience sample with sequential selection of 52 Brazilian ATCs using the Wisconsin Card Sorting Test (WCST), questionnaire applied to the ATCs, Student's *t*-test, and one-way analysis of variance with post hoc Tukey multiple comparisons of WCST with functional characteristics.

RESULTS: ATCs with 0 to 5 yr of service presented scores significantly above the cohort average in the WCST [0-5 yr: 0.54 ± 0.01 vs. 6-15 yr: 0.31 ± 0.52 vs. 15+ yr: -0.02 ± 0.80]. ATCs working a 3-shift pattern presented an efficient performance and fewer perseverative errors in the WCST (3-shift: −0.63 ± 0.38 vs. 4-shift: −0.45 ± 0.43), that did not rise to significance. In a comparison between executive brain functions and technical qualifications, the controllers who worked in the TWR (Aerodrome Control Tower) only, and those who worked in both the TWR and APP (Approach Control Service) showed no differences in the number of completed categories and in perseverative errors.

DISCUSSION: The executive brain functioning of the ATCs, such as mental flexibility, strategic planning and inhibitory control, were identified as being above average when compared to the general population. While alterations in work shifts appear to have a negative (but nonsignificant) impact, newer ATCs showed stronger scores than more experienced ATCs on the WCST. Successful performance as an ATC has complex foundations, such as understanding the context of air navigation and having strong executive function capabilities.

KEYWORDS: Executive functions, air traffic controller, technical qualification, work shifts, length of service.

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In 2018 Brazil recorded a total of 1,289,403 landings and take-offs, according to INFRAERO's (Brazilian Airport Infrastructure Company) Statistical Operational Yearbook.[6] Air traffic control activity to manage this air traffic is necessary for each of the landings and take-offs. The growing number of flights places an increased strain on all Brazilian civil aviation sectors, especially air navigation services, which includes the air traffic control system in general.

The Department of Airspace Control (DECEA), a Brazilian State organization under the Ministry of Defense and Aeronautics Command, is responsible for the strategic and systemic control of the nation's airspace. DECEA is the central body of the Brazilian Airspace Control System (SISCEAB).[10]

The services provided to effectively operate, manage, and maintain control of the airspace demand a high degree of technology, research and planning, and a specialized workforce.

The relevant procedures for the provision of air traffic services are designed to provide greater flight safety, through air traffic management, telecommunications, meteorology, and aeronautical information services. In the entirety of this complex system, the professionals responsible for controlling the aircraft, keeping them a safe distance apart, and maintaining the flow in a secure, orderly and efficient manner, are the air traffic controllers (ATCs).

The ATCs are the professionals in charge of keeping the aircraft traffic in the airspace and at airports more safe, orderly, and efficient. They work by issuing authorizations to pilots, i.e., giving the necessary instructions and information within the airspace under their jurisdiction in order to prevent collisions

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between aircraft, and between aircraft and obstacles in the vicinity of airports.[8] The work of ATCs imposes a great mental and emotional burden on them due to the high level of cognitive tasks. The role requires the ability to withstand situations of stress, to be adaptable, able to concentrate for prolonged periods of time, and to be highly responsible.[27,28]

The aim of this study was to evaluate the executive functions of the ATCs in relation to characteristics of professional activity, such as length of service, technical qualifications, and work shifts. For this research, we evaluated ATCs who worked in the Approach Control Service (APP), which provides radar approach control services to aircraft arriving at or departing from the aerodrome. The overall aim is to maintain separation from other aircraft or obstacles. The jurisdiction area of the APP is the airspace designated as the Terminal Control Area (TMA) or Control Zone (CTR).[7]

We also evaluated the ATCs who worked in the Aerodrome Control Tower (TWR), providing the Aerodrome Service to aircraft in the phases of maneuvering, taxiing, taking off, landing, or overflying the aerodrome. Its main aim is to avoid collisions with other aircraft, obstacles and vehicles moving on the ground. Its area of jurisdiction covers the aerodrome traffic circuits and maneuvering areas.[9]

Over time, the Federal Aviation Administration (FAA) has optimized the system for the recruitment, selection and training of the next generation of air traffic control specialists. Their research has found that skills such as scanning across both auditory and visual sources, perceptual speed and accuracy, information interpretation, sustained attention, long-term memory, problem identification, prioritization, time sharing, information, and processing flexibility and task closure will become increasingly important, given the expansion in air traffic.[11] It is precisely these characteristics that compose the executive functions.

Therefore, this study is justified by the need to identify better ways to measure this sensitivity to the environment and stress, as the ATCs' profession requires extensive involvement of executive functions and the cognitive system.[15] Surprisingly, however, this topic has not so far been the focus of much empirical research.[2] In this study, executive functions were evaluated using the Wisconsin Card Sorting Test (WCST). This test is considered to be able to measure "executive function," requiring the ability to develop and maintain an appropriate problem-solving strategy through conditions of changing stimuli, in order to achieve a future goal.[19,32]

The WCST indicators used were:

Number of completed categories: This measure evaluates the capacity for: abstraction in categorization, mental focus in the face of sensory distraction, and employing new principles of categorization when stimuli vary.[34] It also investigates initiating, modulating or inhibiting mental skills, such as concept formation, categorization, strategic planning, and transformation of thought into action.[16]

Perseverative errors: This measure evaluates failures to recall previous responses and lack of attention or difficulties in inhibiting responses; factors associated with impulsivity.[3] Perseverative errors are characterized as a difficulty updating responses to new context information by inhibiting information that is no longer relevant.[13]

The two WCST indicators used in this study were intended to measure mental flexibility, strategic planning and inhibitory control, which are considered solid measures of executive functioning.[14,18,30]

METHODS

This observational and analytical study correlated measures of executive functions with indicators of demographic and occupational characteristics for a sample of Brazilian air traffic controllers.

Subjects

A total of 52 ATCs participated in this study, belonging to 3 air traffic control units: Unit A, 29 ATCs; Unit B, 12 ATCs; and Unit C, 11 ATCs. Sample selection was characterized as nonprobabilistic with a convenience approach, in which the professionals were selected sequentially until the minimum number of cases for each airport was reached. The subtests of number of completed categories and perseverative errors from the z-score were used for the Wisconsin analysis. All ATCs who agreed to participate in the study signed an Informed Consent Form (ICF). This study was approved by the Postgraduate Program scientific committee and the Research Ethics Committee of the Pontifical Catholic University of RS (PUCRS) under number: 462,813. This research followed the principles set out in the Universal Declaration of Human Rights (1948) and Dana Foundation Neuroethics Symposium (2002).

Materials

Questionnaire applied to the Air Traffic Controllers. Created ad hoc, with the aim of collecting demographic and occupational data, and health conditions. Inclusion of a questionnaire is recommended for any evaluation of executive skills to show different aspects of the daily functioning of the person being assessed.[35]

Wisconsin Card Sorting Test (WCST). Developed by Berg and Grant[5] to assess the capacity for abstraction and ability to alter cognitive strategies in response to environmental changes. A computerized version was used in this study. There are no statistically significant differences between the manual and computerized versions.[36] The results obtained from the WCST were then analyzed using performance indices obtained from the general adult population, taken from the Wisconsin Card Sorting Test Manual: revised and expanded.[20]

Wisconsin Card Sorting Test manual (revised and expanded).[19] The categories used from Table 5 of the manual were: descriptive statistics for age, education, IQ and WCST gross scores of the comparison group normal adults, and the clinical samples. The Normal group indices were used for this study. All the above cited instruments were applied at the same moment in time, 3 h before the work shift began, and the procedure was used for all ATCs.

Statistical Analysis

The results were presented using descriptive statistics through absolute and relative distribution (n-%), as well as through measures of central tendency (mean and median) and variability (SD, range, and interquartile range), where the symmetry of continuous distributions was assessed by the Shapiro Wilk test. One-way analysis of variance with post hoc Tukey multiple comparisons were performed to compare continuous variables between the three independent groups (airports). The data were statistically analyzed using the software SPSS 17.0 (Statistical Package for Social Sciences for Windows) in which the level of significance (α) adopted was 5%.

RESULTS

The mean age of the ATCs evaluated was 37 yr (SD = ±8.5), with a predominance of males 76.9% (*N* = 40). In terms of educational level, 61.5% (*N* = 32) had completed higher education, 26.9% (*N* = 14) had incomplete higher education, and 7.7% (*N* = 4) had a postgraduate qualification.

In relation to the health of the ATCs 18.0% (*N* = 9) reported having a chronic disease, such as hypertension, diabetes, and gastritis (**Table I**). Physical activity was reported by 74.0% (*N* = 37) of the ATCs. According to **Table II**, the mean length of service in air traffic control was 12.1 yr of work, with 36.0% (*N* = 18) having worked between 0 and 5 yr, 34.0% (*N* = 17) between 6 and 15 yr, and 30.0% (*N* = 15) working for more than 15 yr. Functional data, length of service, technical qualification (TWR or TWR/APP), and work shifts (3-shift or 4-shift) were analyzed.

Table I. Sociodemographic Distribution of Air Traffic Controllers.

VARIABLES	SAMPLE TOTAL (*N* = 52)	
	N	%
Sociodemographic Data		
Gender		
Female	12	23.1
Male	40	76.9
Age [Mean ± SD (Range)]	37.9 ± 8.5 (24 - 61)	
Age Group		
Up to 39 yr	30	57.7
40 yr or more	22	42.3
Schooling*		
HSC	2	3.8
HEI	14	26.9
HEC	32	61.5
Postgraduate	4	7.7
Health Data		
Physical Activity†		
Yes	37	74.0
No	13	26.0
Chronic Disease*		
Yes	9	18.0
No	41	82.0

*Education - HSC: high school complete; HEI: higher education incomplete; HEC: higher education complete. †Data missing (DM): Physical activity - 2 (3.8%); Chronic disease - 2 (3.8%) Source: Authors, 2020.

Table II. ATC Functional Data.

VARIABLES	TOTAL SAMPLE (*N* = 52)	
	N	%
Air Traffic Control Unit (airport)		
A	29	55.8
B	12	23.1
C	11	21.2
Time working (years)* [Mean ± SD (Median)]	12.1 (± 9.6) (12.0)	
Length of time working in the activity*		
Up to 5 yr	18	36.0
From 5 to 15 yr	17	34.0
More than 15 yr	15	30.0
Technical Qualification†		
TWR	24	46.2
APP	1	1.9
TWR and APP	27	51.9
Shift Work‡		
3-shift	23	44.2
4-shift	29	55.8

Notes: *Data missing (DM): Time working - 2 (3.8%); Physical activity - 2 (3.8%); Chronic disease - 2 (3.8%); †Technical qualification - TWR: aerodrome control tower; APP: approach control center; ‡Work shifts: 3 shifts (airport B and C); 4 shifts (airport A). Data obtained through a questionnaire completed by all ATCs. Source: Authors, 2020.

The WCST has not yet been validated for use with a Brazilian population and, therefore, we used a z-score to analyze our results, as a basis for comparing the results obtained. In analyzing these two subtests (Number of completed categories in **Fig. 1** and Perseverative Errors in **Fig. 2**), we used the z-scores calculation to map the performance curve of the group herein studied. The indices for the adult population without injury was used, taken from the reference table in the WCST Manual.

Number of Completed Categories. Results from the assessment of capacity for abstraction and ability to change mental strategies in response to environmental changes revealed an average raw score of 5.6 (SD = ±0.8), with the highest concentration of

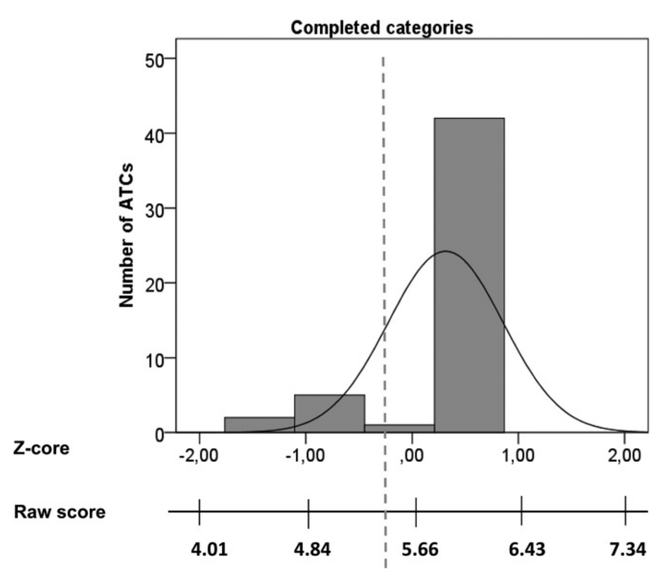

Fig. 1. Number of completed categories: Wisconsin Card Sorting Test (WCST).

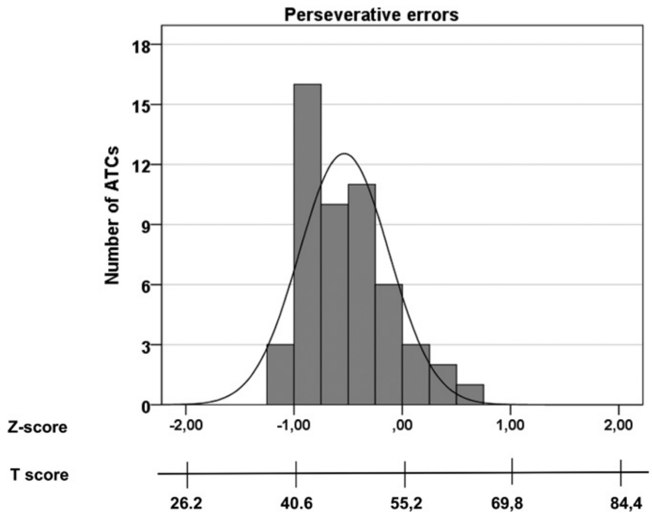

Fig. 2. Perseverative errors in the Wisconsin Card Sorting Test (WCST).

correct answers occurring in category 6 (maximum correct answers) (84.0%, $N = 42$), as shown in Fig. 1.

Estimates detected for the ATCs' z-scores showed them to be higher (0.32 ± 0.54) when compared to the general adult population data ($t_{(49)} = -36.611$; $P < 0.001$). This above-average score is statistically independent of schooling, work shift, technical qualification and length of service.

Perseverative Errors. In relation to the ability to inhibit wrong answers, the average raw score was 7.3 points with a standard deviation of 7.8 points, signifying a good performance with fewer errors, when compared to the general adult population that has an average score of 12.92 points with a standard deviation of 12.46 points (Fig. 2).

In order to conduct a comparative analysis of the results obtained in the WCST, the results were separated by functional characteristics: work shifts, technical qualification and length of service (**Table III**).

As can be seen in Table III, ATCs with a period of service of 0–5 yr performed better in the WCST subtest number of categories completed, with a statistical significance of 0.018, followed by the group with 6–15 yr of service. When analyzing the results by work shifts and technical qualification, the scores obtained in the WCST were not significant. No significant differences were found in perseverative errors for any of the functional characteristics (Table III).

DISCUSSION

The results of the executive function testing indicated that controllers performed better than the general adult population. Assessment of executive functions revealed an above average performance in the ATCs group with 0 to 5 yr of air traffic control activity, when comparing executive function and length of service (Table III). This group presented more positive results in the completed Number of Categories subtest, which evaluates the number of correct tasks from those that require the capacity for abstraction and strategies in response to environmental changes.

It should be noted that the average age of the group with 0–5 yr of service as an ATC was 31.33 yr, while the average age for the groups with 6–15 yr and 15+ years of service were 37.06 yr and 47 yr, respectively. Thus, a positive correlation between age and length of service was identified, where less time working as an ATC is associated with younger age.

The efficiency of services in air traffic control does not depend on isolated factors, such as rotating shift pattern or length of service. Rather, its efficiency is based upon the availability of methods of communication, navigation, and surveillance; adequacy of the installed technical resources in the control units; and on the qualification of human resources, including the cognitive ability of air traffic controllers.[33] However, in this study, except for length of service, no other variables created significant differences between our cohort groups. A combination of cross-sectional and

Table III. Mean (± SD) of Each Variable and WCST Results, According to Work Shifts, Technical Qualification, and Length of Service.

EXECUTIVE FUNCTION	INSTRUMENT	FUNCTIONAL CHARACTERISTICS	TEST ANALYSIS MEAN	SD	*P*
		WORK SHIFTS			
Categorization	WCST N° of categories completed	3 shifts	0.31	0.55	0.951€
		4 shifts	0.32	0.55	
Cognitive Flexibility	WCST Perseverative errors	3 shifts	–0.63	0.38	0.126€
		4 shifts	–0.45	0.43	
		TECHNICAL QUALIFICATION			
Categorization	WCST N° of categories completed	TWR	0.40	0.39	0.282€
		TWR and APP	0.24	0.65	
Cognitive Flexibility	WCST Perseverative errors	TWR	–0.63	0.29	0.100€
		TWR and APP	–0.44	0.48	
		LENGTH OF SERVICE (yr)			
Categorization	WCST N° of categories completed*	0–5	0.54a	0.01	0.018 ʆ
		6–15	0.31b	0.52	
		15+	–0.02c	0.80	
Cognitive Flexibility	WCST Perseverative errors	0–5	–0.56	0.62	0.944 ʆ
		6–15	–0.52	0.51	
		15+	–0.51	0.44	

Source: Authors, 2020; €: Student's *t*-test for independent groups; ʆ: One-way Analysis of Variance – post hoc Tukey, where mean estimates between categories of the same variable, followed by the same letters, do not differ at a significance of 5%. *Multiple comparisons: 0-5 vs. 6-15 ($P = 0013$); 0-5 vs. 15+ ($P < 0001$); 6-15 vs.15+ ($P = 0029$).

longitudinal approaches might be used in the future to distinguish how pre-existing vs. acquired cognitive control functions are modified by experience in young adults.[2]

One hypothesis for the aforementioned result of a better performance by the ATC group who have up to 5 yr of experience could be a reflection of their greater exposure to technological and virtual stimuli. We identified this age group as having participated in a social period of intense contact with new technologies, which may have allowed them to be more comfortable more quickly in the computerized testing environment compared to older ATCs. However, all ATCs are working in a highly technological environment.

A second hypothesis for this small difference and variation in scores between the group with 0–5 yr of service and the group with 15+ years of service may be related to age, as this less experienced group has a lower mean age.

Although there is statistical significance between the ATCs with less time of service and higher scores in the Number of Categories Completed subtests in the WCST, this hypothesis may not be sufficient, since the ATCs with more than 15 yr of service have more experience when compared to the 0–5 yr group. We suggest that future studies measure cognitive versatility vs. length of service and technical skills.

As the ATC workforce reaches nearer to retirement age, cognitive changes might reduce the performance of these controllers.[22] However, other data suggest that age-related decline in actual work performance may be delayed by greater experience.[4,21,31] This may be the case when considering ATCs.[22]

We found an interesting historical difference in the ATCs' work environments: the constant growth in aircraft flow in their respective airports. The ATC group with the shorter career span (0-5 yr) has not experienced upward growth in the number of aircraft requiring air traffic management. A third hypothesis is that this less experienced group began their careers with this increased workload already in effect. This may have created a cognitive advantage for them, since their work experience required adaptation and learning in this scenario of high aircraft flow (Table III).

Finally, a fourth hypothesis could be that newer ATCs are actually trained differently in preparation for their jobs than the ATCs trained more than 5 yr ago. Newer training techniques may actually focus upon and strengthen the type of skills measured by the WCST. The training curriculum has changed over the years to strengthen the executive function cognitive abilities that are so valuable in controlling airspace traffic. This enhanced training and skills development could be reflected in the differences in these ATCs' WCST scores.

Two important groups were considered in order to relate executive function with work shift patterns: the ATC group working 3 shifts (morning, afternoon, night); and the ATC group working 4 shifts (morning, afternoon, night, and dawn). Both of the operational work schedules (4 shifts and 3 shifts) are rotated daily and have a minimum interval between one shift and another of 11 h. ATCs working a 3-shift rotation have 1 d off after 3 d of work and those working a 4-shift rotation have 1 d off after 4 d of work. In this context, assessment of the mental flexibility and strategies of the group working a 3-shift pattern revealed a lower number of errors in comparison to the group working a 4-shift pattern. The 3-shift pattern group performed better in the evaluation of executive functions, but without a significant statistical difference. Studies on the effects of rotating shifts in ATC duties, in general, show changes in cognitive performance both in planning and decision-making. Night work and certain types of shift work rotation patterns can subject workers to adverse physiological and psychological effects. People affected by circadian dysrhythmia experience subjective drowsiness, reduced performance capacity, insomnia, increased health risks, uncontrolled sleep episodes, and an increased potential for accidents. [1,25]

Professionals submitted to working rotating shifts, such as the ATC, are affected by numerous factors that lead to a decrease in performance, such as fatigue and sleep deprivation. A serious problem associated with this drop in performance is a greater propensity for errors to occur in the work environment, among them, perceptual errors.[26] Although a full review of the performance effects of rotating shifts is not within the scope of this article, factors such as sleepiness and fatigue must be considered when analyzing the differential scores among ATCs working 3-shift and 4-shift patterns. Using the Epworth sleepiness scale (ESS) to investigate the ATC groups identified that 25.0% ($N = 13$) of the total sample reached scores indicative of Excessive Daytime Sleepiness (EDS), and of these, 84.6% ($N = 11$) belonged to the Air Traffic Control Unit A, which has a 4-shift rotating work schedule.[17]

ATCs who work these alternating shift regimes have shown effects related to this system of scheduling, especially when performing night work activities. The main alterations found relate to quality of sleep, drowsiness during the shift, fatigue, stress, mood swings and a decrease in the state of alertness and vigilance. These symptoms are associated with changes in circadian rhythm, which are caused by irregular shift times.[24] It is therefore evident that the central factor is not the work shift itself, but the rotation of these work shifts. Shift changes appear to carry great importance, as sleep periods are altered, and cognitive and physiological conditions affected.

Correlation of the ATCs executive functioning and technical skills revealed no statistically significant differences in tasks involving mental flexibility, strategic planning, and inhibitory control, when comparing the scores obtained from the ATCs operating TWR and those professionals operating TWR and APP simultaneously. Although they are different operational modalities, they require key executive skills in controlling landing and take-offs, avoiding collisions between aircraft and maintaining the orderly and safe flow of air traffic.[7,10] There are many theoretical references stating that airspace control can be defined as a complex system of interdependent elements that interact in an organized manner, based on simple but nonlinear rules.[23,29]

Nonetheless, the rules may be simple in isolation, but ATCs apply multiple rules to an aviation environment whose elements do not always interact predictably. This results in a sometimes very complex system.

Mental flexibility, strategic planning and inhibitory control, when efficiently integrated, represent not only good executive functioning, but also are determining factors for the safety of airspace control.

The Command Instructions of the Ministry of Defense and the Air Command note that technical skills are not unrelated to nontechnical skills, which are defined as cognitive, social and self-management skills that complement the technical abilities of professionals and contribute to safety and the effective performance of tasks.[10] Therefore, the work of the ATC requires professionalism and effective cognitive strategies to safely manage airspace control.

In this study, we chose the WCST to assess executive function parameters because we believed it would effectively identify differences in a cohort of ATC professionals. The WCST is useful for measuring the abilities: to focus, to retain information and work with it, to filter out distractions and to shift strategies due to unexpected changes. These abilities are needed when managing an air traffic system in a busy airport. These skills, which help an ATC focus on multiple streams of information, while at the same time monitor for errors, make decisions and strategically plan actions, are associated with the neuropsychological testing measures of "executive function." [12,14]

This research could be described as a preliminary study in which a limited number of controllers were tested to determine whether the results were sufficiently promising to support collecting more data in a future study.

Finally, the present study revealed that ATCs demonstrated above average executive functioning capabilities (mental flexibility, strategic planning, and inhibitory control) in comparison to the general population.

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