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The impact of neurosurgical procedure on cognitive resources: Results of bypass training

Antti Huotarinen, Mika Niemelä, Ahmad Hafez

Department of Neurosurgery, Helsinki University Hospital, Helsinki, Finland

E-mail: Antti Huotarinen - ahuotarinen@me.com; Mika Niemelä - mika.niemela@hus.fi; *Ahmad Hafez - ext-ahmad.hafez@hus.fi
*Corresponding author

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Abstract

Background: Neurosurgeons are exposed to unavoidable distractions in their natural operating environment. Distractions can affect both the surgeon's concentration and the safety and duration of the surgery. Such distraction can be studied by applying a simultaneous cognitive task during a surgical procedure.

Methods: We used a previously described cognitive task: a forward (DF) and backward digit (DB) repetition task to interfere with the surgeon's attention during a training bypass. A pilot study was performed to find suitable digit repetition lengths. For the main experiment, we used four-digit strings. The test task was alternated across two consecutive sutures ($n = 153$, 8 bypasses), followed by two consecutive control sutures without digit repetition. The duration and the number of correct answers for the digit repetition task were compared to a baseline digit repetition without simultaneous surgery.

Results: During the bypass surgery, digit repetitions (especially DB) became slower ($P < 0.0001$). More errors were made during DB compared to DF only during simultaneous bypass ($P < 0.0001$). However, we found no effect of digit repetition tasks on individual suture times ($P = 0.823$).

Conclusions: The ability to engage in simultaneous tasks while performing surgery is diminished. A surgeon with extensive training can withstand external distraction without an effect on performance; however, this is achieved by partially ignoring the simultaneous task. Our data support that during surgery other cognitive tasks should be avoided to ensure safety.

Key Words: Bypass surgery, cognitive distraction, neurosurgery

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INTRODUCTION

During surgery neurosurgeons are exposed to different kinds of distraction, such as operating room (OR) staff and equipment movement, questions from observers, residents, and others, and phone consulting. Several authors have studied the effects of distraction and interruption during clinical practice in many fields of healthcare, especially in the OR.[8,28,30,35] Distractions during operations can risk patient safety[14,36] and result

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in prolonging operations.[40] Intermittent auditory and mental distractions also have a profound effect on surgeon performance, especially with novice surgeons.[26] As in most surgical fields, the complexity of neurosurgery requires a high level of concentration and superior fine-motor skills. It is clear that, among other factors, successful surgical outcomes are strongly correlated with full focus and distraction control. Nevertheless, the effects of distraction on performance are different between experienced and novice surgeons.[20] To our knowledge, there have been no studies on the effects of distraction specifically focused on neurosurgery.

Bypass surgery is a highly complex skill with high time pressure. Mastering it requires both extensive practice and a strong ability to concentrate, i.e., sustain focused attention during the actual procedure. Attention and working memory have been shown to be closely related processes.[5] Working memory is thought to be a temporary information storage of limited capacity that provides an interface between perception, long-term memory, and action.[6] Working memory capacity has been shown to affect visuospatial attention control, measured by the ability to control eye movement patterns.[25,37] We have previously shown this to be an element of good performance in microneurosurgery.[10] It has also been shown that working memory capacity contributes to motor skill learning.[34] While it seems obvious that performing bypass surgery reserves a considerable amount of working memory and the surgeon's ability to complete other cognitive tasks is impaired, our novel data prove it in this study.

Repetition of auditory cued digit strings of various lengths is one method of measuring working memory capacity and is used as a central part of the Wechsler Adult Intelligence Scale (WAIS), designed by psychologist David Wechsler and first published in 1955. The normal lengths for forward (DF) and backward (DB) repetition of digit strings are described for various populations;[4] and both are sensitive, e.g., for aging.[7] It has been shown that both DF and DB activate shared and distinct neural networks,[12] and it has been suggested that DB, in particular, relies on visuospatial imagery.[12,19] DF and DB have been used in various dual task experiments as external cognitive loads to disrupt other simultaneous tasks. Digit repetition, memorization-based working memory, and cognitive loading have been shown to have negative effects on various tasks requiring attention, ranging from gambling performance[18] to soccer-related decision-making in both nonexpert soccer players and expert players who encode and store abstract representations of visual patterns in memory.[27]

Our aim was to develop and test a method based on previously simulated training models as well as psychological studies that examine controllable and quantifiable cognitive loading during microsurgical training, and to study cognitive requirements and distractibility during bypass surgery. Our hypothesis was that even trained surgeons are susceptible to outside cognitive distractions while performing complex tasks such as bypass training, and that multitasking with digit repetition (both DF and DB) can impair bypass performance, and that the digit string memory tasks are significantly affected by simultaneous bypass suturing.

MATERIALS AND METHODS

In this experimental study, all training bypass procedures were end-to-side procedures, simulating the most common superficial temporal artery to medial cerebral artery (STA-MCA) bypass procedure. It was performed by the last author (Ahmad Hafez), who performed 1,300 different training bypass procedures over the past 3 years, between June 2014 and July 2017, in the Department of Neurosurgery, Helsinki University Hospital, Helsinki, Finland.

Study design

The main rationale for the experiment was to compare individual suture times during multitasking with digit repetition (both DF and DB) to individual suture times without a digit repetition task. For this purpose, we designed experiments wherein the digit repetition task and the control (no repetition task) were alternated over one or two consecutive sutures during training bypass procedures.

Pilot 1

Pilot 1 was a feasibility experiment designed to find the range of string-repetition lengths possible during suturing under the microscope.

Digit strings were read aloud by the researcher, without a pause after the answer. Each digit repetition task lasted for one interrupted suture. Digit repetition lengths were 3, 5, and 7 digits for the forward repetition task, and 3 and 5 digits for the backward repetition task [Video 1].

In this pilot, the procedure was a single end-to-side bypass on a 1 mm silicone wet tube with 10-0 sutures. The bypass was recorded on video and the times for individual bypasses were analyzed from the video.

Pilot 2

Pilot 2 was designed to confirm that the chosen four-digit string forward (4-DF) and backward (4-DB) repetition tasks were suitable for the actual experiment.

The four-digit strings were read by a synthesized female voice at one digit per second with a 6-second pause between each four-digit string to allow time for answering. The 4-DB repetitions were tested with and without surgery and compared against a control task of 4-DB repetitions without surgery.

Main experiment

In the main experiment, there were three groups of bypasses: control without any digit repetition tasks ($n = 2$), bypass with simultaneous 4-DF task ($n = 2$), and bypass with simultaneous 4-DB task ($n = 3$) [Figure 1a, *bottom*]. During the digit repetition bypasses, the string repetition task (either 4-DF or 4-DB) was performed on two consecutive sutures. This was followed by two consecutive sutures during which there was no repetition task [Figure 1a, *middle and dotted circles top*]. The baseline for 4-DF and 4-DB repetition was controlled at both the beginning and the end of the experiment without simultaneous surgery [Video 2].

Surgery

Surgery was done with an OPMI pico tabletop microscope (Zeiss, Jena, Germany) [Figure 1b]. The pilot test surgery was end-to-side bypass with a 1 mm wet tube. Interrupted sutures were made with 10-0 microvascular practice suture needles (Muranaka Medical Instruments, Tokyo, Japan), with thread cut to a 5–6 cm length at the start of the individual bypass procedure. Bypass suturing was performed in the same order, starting from two hanging sutures on the axial ends of the bypasses, followed by two additional hanging sutures in the middle of both sides [Figure 1a, *top*]. The four hanging sutures [black lines in Figure 1a, *top*] were considered to be the baseline and were always performed without any digit repetition task. The aim was to have four sutures on each of the four sides of the scaphoid-shaped bypass formed by the first four hanging sutures, totaling 20 sutures for each bypass, including the baseline sutures [red lines in Figure 1a]. For the main experiment, the training surgery was an end-to-side performed on a chicken wing artery, a commonly used model to practice bypass surgery.[17] The diameter of the arteries was 1 mm, measured with scale on background from video.

Video capture and analysis

Webcam C930e (Logitech, Lausanne, Switzerland) was connected to the microscope and connected to a MacBook Pro (Apple Inc., Cupertino, CA, USA) that captured video with QuickTime (Apple Inc., Cupertino, CA, USA) at 720p video quality. Video analysis was done on Final Cut Pro X (Apple Inc., Cupertino, CA, USA) at 50 frames per second.

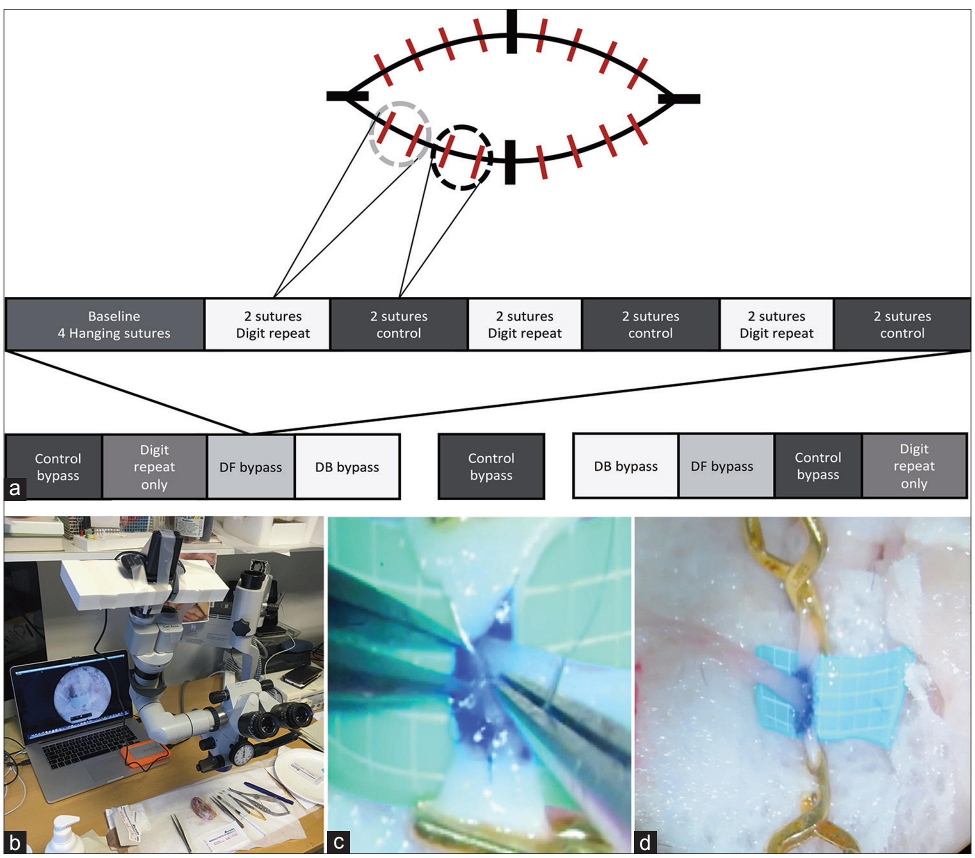

Figure 1: Study design for the main experiment. (a) ***Top:*** **Bypass suturing scheme showing the first four hanging sutures (black) and sutures on each side included in the digit repetition analysis (red), two consecutive sutures (*dotted circles*).** ***Middle:*** **Outline of sutures during bypasses with digit repetition task and control sutures without digit repetition tasks in the main experiment. During each individual bypass, the task was four-digit repetition either forward or backward.** ***Bottom:*** **Organization of the four-digit repetition task baselines without simultaneous bypass (digit repetition only), digit repetition bypasses (DF and DB), and control bypasses during the main experiment. (b) Instrumentation for the bypass and video capture. (c) A screenshot of wall piercing during suturing in one of the bypasses. (d) Completed bypass just prior to removing the temporary clips**

Suturing times were measured from video. The time needed to complete a single suture was measured from picking up the needle to picking up the needle before the following suture. We also recorded the times for each suture's subcomponents: needle pick up, wall piercing [Figure 1c], thread pull, knot and cut, the interval between knot and cut, and picking up the needle for the following suture. The handedness for needle control and knot tying was recorded from video.

Digit repetition analysis

All digit repetition analysis was performed from recorded audio separately from the video analysis. We measured the time for the answer as the interval between the last audible part of the final digit of the task string and the last audible part of the final digit of the answer. The correctness of answers was measured from the recorded audio. The number of correct digits in each answer string was scored individually.

Statistics

All statistical comparisons between multiple groups were done with one-way analysis of variance (ANOVA) for parametric variables and with Kruskal–Wallis for nonparametric variables. All analysis was done using Prism 7.0b (GraphPad, San Diego, USA) software.

RESULTS

Pilot 1

Only 5-DB digit repetition times were significantly longer than the baseline 3-DF repetition during the control task (no surgery) (ANOVA $F[9,67] = 20.5$, $P < 0.0001$, Dunnett's multiple comparison, $P < 0.0001$). During the surgical bypass task, the digit repetition times were longer than baseline for the 7-DF repetition (Dunnett's multiple comparison, $P = 0.028$), 3-DB repetition (Dunnett's multiple comparison, $P = 0.0001$), and 5-DB repetition (Dunnett's multiple comparison, $P = 0.0001$) [Figure 2a]. The quotient of correctly repeated digits per respective digit string length was lower for 5-DB repetition during both the control and the surgical bypass tasks (ANOVA $F[9,68] = 4.537$, $P = 0.0001$, Dunnett's multiple comparison, $P < 0.005$ for both). However, during the 5-DB repetition task, the surgeon experienced considerable stress and frustration; this led to commenting that the repetition task was too hard. There was no significant difference in individual suture times in Pilot 1 (ANOVA $F[5,10] = 1.01$, $P = 0.464$).

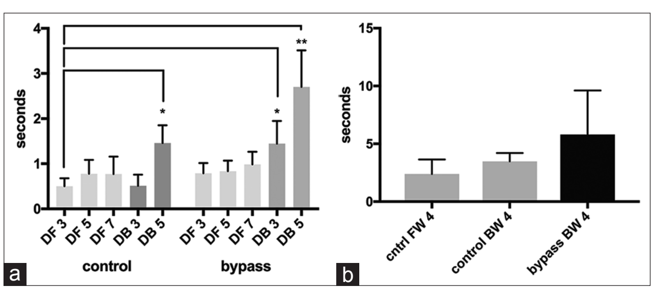

Figure 2: (a) Pilot 1 results showing the increase in the duration of digit repetition times as digits per second for DF and DB repetition and different digit string lengths during control (no surgery) and bypass training surgery. (b) Pilot 2 results of digit repetition times for digit repetition times without simultaneous bypass training (control forward and control backward) and during bypass training (bypass backward). ***Error bars represent SD, DF, DB***

Pilot 2

Answer time was significantly longer during surgery with 4-DB compared to 4-DF without surgery (ANOVA $F[2,20] = 3.862$, $P = 0.038$, *post hoc* Tukey $P = 0.0366$) [Figure 2b]. Subjectively, the 4-DB repetition task was found to be demanding but not the cause of very high stress or frustration. This digit length was determined to be suitable for the main experiment.

Main experiment

The average time for a completed bypass [Figure 1d] was 17.43 min (SD 1.863; for study groups, see Table 1) for the eight bypasses performed [Figure 3a]. There was no difference in complete bypass times (ANOVA $F[2,5] = 0.203$, $P = 0.823$). On average, 19.1 sutures (SD 0.599) were made per bypass for a total of 121 individual sutures in addition to 32 hanging sutures.

Average time for individual side sutures (non-hanging sutures) was 45.9 s (SD 13.2). There was no difference between the time needed for individual sutures between study groups (ANOVA $F[4,116] = 0.163$, $P = 0.956$). Baseline hanging sutures were slower than side sutures in all study groups (all *t*-test $P < 0.025$) [Figure 3b; Table 1]. We also analyzed durations of the subcomponents of the sutures, and found no significant differences between sutures with digit repetition tasks and the control sutures. However, there was a statistically significant correlation showing that sutures done later in the study were faster (Pearson correlation -0.275, $P = 0.003$).

Digit repetition

During the bypass, the repetition of four-digit strings was slower for both 4-DF and 4-DB repetitions than for similar repetitions without bypass. In addition, the 4-DB were slower compared to the 4-DF, both without the bypass and during the bypass [Figure 3c] (Kruskal–Wallis test $H = 251.3$, degree of freedom (d.f.) $= 3$, $P < 0.0001$; all Dunn's *post hoc* tests were significant: control forward vs. control backward task, $P = 0.0239$; in all other nonparametric *post hoc* tests $P < 0.0001$). During the bypass, the number of correct answers was lower; in addition, the average number of correct digits was lower for the 4-DB compared to the 4-DF only during the bypass [Figure 3d] (Kruskal–Wallis $H = 155.5$, d.f. $= 4$, $P < 0.0001$; Dunn's *post hoc* test was significant at $P < 0.0001$ for all other tests but not for 4-DF vs. 4-DB without surgery). During surgery, the

Table 1: The average duration of sutures, duration of answers, and the number of correct answers during each study group

	n (sutures/digit repeats)	t suture	SD	t answer	SD	Correct answer%	SD
Hanging sutures	32/0	60.82	12.80	NA		NA	
Control	51/0	46.08	13.73	NA		NA	
Bypass DF	16/68	44.44	9.41	3.222	1.236	72.47	38.1
Bypass DB	24/103	46.11	11.66	4.142	1.154	51.22	38.52
Digit only-DF	0/92	NA		1.18	0.4928	93.62	24.16
Digit only DB	0/97	NA		1.987	0.7537	98.47	11.25

NA: Not applicable, SD: Standard deviation

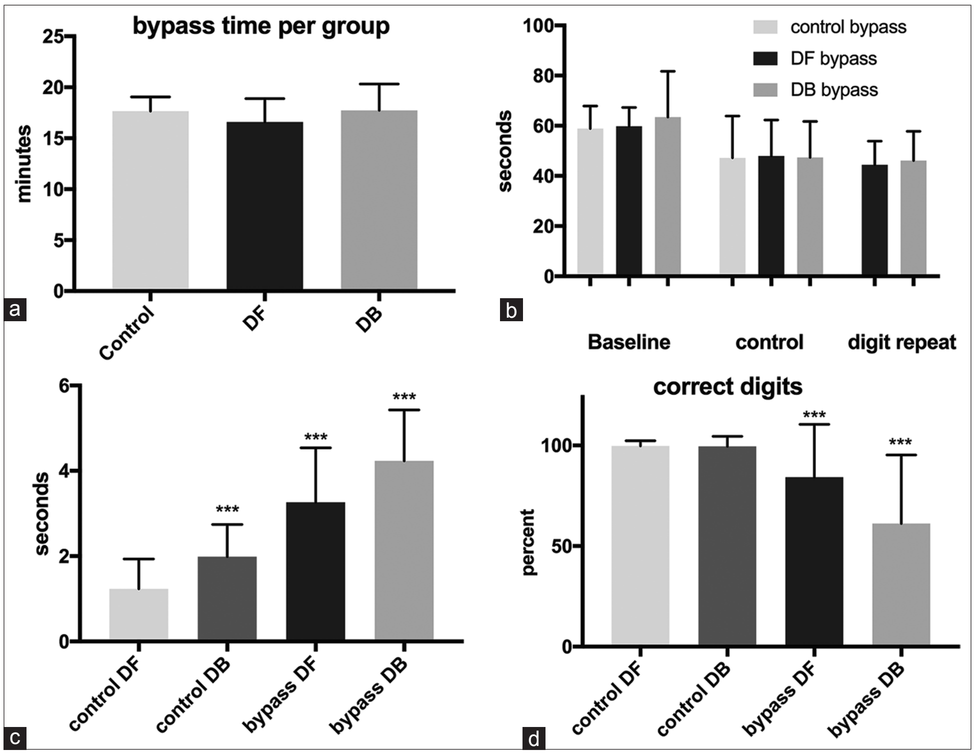

Figure 3: (a) Bypass times during the main experiment showing no difference between study groups. (b) Individual suture times during the main experiment separated for the bypass (control or dual task), task type during the bypass (control, DF, or DB) and first four sutures (BL) showing no differences between study groups. (c) Answer durations during the main experiment for digit repetition without simultaneous bypass training (control DF and DB) and digit repetition times during simultaneous bypass training (bypass DF and DB). (d) The average number of correct digits produced during without simultaneous bypass training, during bypass, and only during bypass is the number of correct answers decreased *Error bars represent SD; *P* < 0.005, **P < 0.0001; DF, digit repeat forward; DB, digit repeat backward*

surgeon felt considerable tension during the 4-DB task and commented on it several times.

DISCUSSION

This study focused on the effects of distraction during surgery, which occurs frequently in neurosurgical practice. It is the first study we are aware of that quantifies and evaluates the effects of simultaneous cognitive tasks during one of the most complex procedures in neurosurgery—the bypass procedure.

We demonstrated that simultaneous cognitive distraction had minimal or no effect on surgical performance; this could be explained by the shifting of attention to the most relevant task, the bypass. However, the bypass task had a significant effect on the digit repetition task, as shown by the increase in time needed to answer and the decrease in the number of correct answers. This implies that the solution to retaining adequate mental resources needed for the bypass is partial or total neglect of the other mental task.

Allocation of limited cognitive resources (i.e., attention) remains a major factor during neurosurgical procedures. Multitasking, which is an attempt to perform two or more tasks simultaneously, is an important ability for the neurosurgeon. However, during multitasking, more mistakes are made or performance is slower as the surgeon's attention is distributed among the tasks.[5,38] When a task is automatized, performing that task requires less of the individual's limited resources for attention, even during a simultaneous task. However, other factors contribute to our ability to concentrate on many simultaneous tasks, such as anxiety, task difficulty, and skill.[38] Music, for example, could give benefit at certain times, as it provides beneficial arousal.[13] A bypass procedure provides a strong task-related stimulus so that the neurosurgeon can concentrate most of his or her attention on the bypass surgery and ignore other simultaneous tasks, which explains our results.

The expert neurosurgeon relies on reflexive manual maneuvering and sustained focus achieved by overlearning the skill so that it becomes automated and not easily affected by outside interference, as is also seen in this study. However, this automatization requires extended training, especially for the bypass procedures. Novice neurosurgeons have no opportunity to master bypass surgery through real surgery because of its infrequent use in clinical practice.[31,39] The acquisition of specific skills in neurosurgery, while coping with the stress and pressure of operations, necessitates the development of alternative training models.[1,2,23] Furthermore, bypass surgery is a challenging procedure and demands long-term dedicated laboratory training.[16,17,21,33] Compared to an actual OR environment, bypass training might be performed in a more relaxed environment with less outside distraction; however, this could lead to overestimation of surgical abilities. Although the OR environment should support performing the surgery, there is inevitable background noise in[22] as well as distractions.[15] It has been proven that background noise inside the OR affects clinical reasoning, especially in junior residents.[11] It has also been shown that noise can generally have psychological and physiological effects on humans, especially when performing critical tasks.[32] We argue that outside cognitive distractions, such as described in our study, should be occasionally applied during lab training to provide a more realistic environment and to ensure that a satisfactory level of skill is achieved to provide resilience to the inevitable outside interference experienced during actual clinical surgery in the OR.

Recent advances in virtual reality technology can enhance surgical training and provide the opportunity for detailed feedback and performance evaluation. It is not far in the future that detailed virtual reality neurosurgical modules will evolve to be a part of training programs in neurosurgery.[3,9,29] With these methods, it will be interesting and beneficial to evaluate not only the technical part of neurosurgical training but also the outcome in a distractive and disrupted atmosphere, similar to what is experienced during real surgery.

This study was conducted without risk of harm to patients since it examined cognitive distraction in the laboratory, during training bypass surgery. The study provided information on the cognitive requirements of bypass surgery and can predict some issues regarding the safety of neurosurgical practice in general. It also connects the literature on neurosurgical training to psychological and cognitive literature, which can help us further deepen our understanding of the cognitive and attentional requirements of neurosurgical operations in general.

Our data show that digit repetition performance was worse during practice bypass compared to the control task without surgery, showing a quantifiable cognitive cost of bypass surgery. However, a simultaneous digit repetition task during bypass did not have an effect on bypass performance, as measured by the time needed to complete individual sutures; this might be explained by a capacity to increase overall attentional control during multitasking or the tendency to ignore the secondary cognitive task during bypass. It is also possible that the cognitive task used in this study was not sufficiently challenging. However, in our pilot study, we found that longer backward digit repetitions were not feasible. It is also possible that the distracting cognitive task should have been of a different type to have a negative effect on bypass performance. However, the capacity to perform the simultaneous cognitive task was very clearly affected, which suggests that the backward digit repetition process in particular relies on some of the same cognitive and attentional processes that are required for bypass surgery. In addition, it has been recently described that attentional control can either improve or deteriorate under pressure in an experimental setting.[24]

Limitations

The main limitation is that this study includes only a single surgeon, so the results might reflect in part his personal traits and the very high volume of bypass training he underwent in previous years. Although it is an attractive study with important findings, it is less realistic than naturalistic observation; however, such observation is difficult to apply during clinical neurosurgery due to safety concerns for the patient. Although all bypasses were inspected to ensure equal quality, this parameter was not discussed, as it did not affect the main scope of the study. However, we are in the process of preparing many studies focusing on training quality in neurosurgery.

CONCLUSIONS

We conclude that the ability to engage in a secondary task while operating is diminished, especially when the secondary task becomes more complex. The presence of simultaneous distraction, especially during a highly demanding task, could negatively impact the automaticity of surgical performance. Time and intensity of distraction, as well as the experience of the neurosurgeon, can all affect the outcome of the surgery. For the patient's safety and excellent neurosurgical outcome, it is important to recognize the type and the level of distraction and interruption with which an individual neurosurgeon can cope. Our data recommend that extra cognitive tasks should be avoided during surgery to ensure safety.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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