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# Evaluation of User Performance in Simulation-Based Diagnostic Cerebral Angiography Training

Oleksiy Zaika
*Western University*, ozaika@uwo.ca

# Evaluation of User Performance in Simulation-Based Diagnostic Cerebral Angiography Training

by

Oleksiy Zaika

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## Abstract

Simulation of anatomically complex procedures, such as angiography, is becoming more practical, however, computer-based modules require extensive research to assess their effectiveness. We organized two training schemas – alternating cases and consistent cases – and hypothesized that the alternating practice cases would be beneficial to test performance. Eight residents (4 radiology/4 neurosurgery) and 8 anatomy graduate students were trained on the Simbionix™ simulator in order to assess skill acquisition in diagnostic cerebral angiography over 8 sessions. We found that participants improve on total procedure time and total fluoroscopy time ($p<0.05$), but not on contrast injected or roadmaps created. There were no significant differences between alternating and consistent training types. Additional work needs to be done with higher sample numbers and visuospatial scores as criteria.



## Keywords

Angiography, aneurysm, simulation, medicine, radiology, neurosurgery, training, simulation-based medical education

# Co-Authorship Statement

The written material in this book is the original work of the author. Oleksiy Zaika contributed to the following aspects of this work: participant recruitment, data collection, data analysis, and authorship of this thesis.

Dr. Sandrine de Ribaupierre developed the original research question and played an integral role in the progression of this study. She was involved in editing conference submissions and contributed her expertise in the field of simulation.

Dr. Ngan Nguyen played a key role in developing research design, research material, and participant recruitment. Her groundwork with this simulator made this thesis possible.

Dr. Roy Eagleson contributed guidance towards new ideas, edited conference abstracts, and assisted with technical work.

Dr. Mel Boulton contributed clinical authentication of methods and provided Angio suite preparation.

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Table of Contents

# List of Tables (where applicable)

# List of Figures (where applicable)

# List of Appendices (where applicable)

# 1 Introduction

## 1.1 Changes in Medicine

The issue of surgical training was first discussed in a presidential address in 1907, when Dr. Dudley Allen stressed that the ideal surgeon "should limit his personal service strictly to those fields in which he is the master…" Since then surgical internship has taken a few forms. At that point, the surgical training system was strictly pyramidal, borrowed from the German medical system, where only about half of the residents coming into the program received the full four-year education in surgery (Pellegrini, 2006). Edward Churchil, who stipulated that "half a surgical training is about as useful as half a billiard ball", famously criticized this system. It was him who introduced the currently used 'rectangular' system, which takes in fewer residents, but provides all with the necessary four-year education. Interestingly, he also advocated for a flexible curriculum to accommodate for individual training needs, however, to this day the rectangular system persists with only minor modifications and a 'frozen-curriculum' (Pellegrini, 2006).

The residency model has retained its core goals and has only recently reached a pivot point where new educational techniques are beginning to be explored and implemented (Pellegrini, 2006). Technological developments and pedagogical research are establishing themselves as influential cornerstones in the movement to provide appropriate complementary training to medical residents.

One of the pivoting forces in the evolution of the medical education system is the increasingly open understanding and discussion of the shortcomings of the traditional training methods used in medicine. The current apprenticeship model raises a few concerns:

- Patient safety, as the trainees often have their first attempts conducting the procedure on the patient (Nelson et al., 2014), and extend the overall procedure time when present (Babineau et al., 2004).
- Limited variety and complexity of cases within rotations (Nelson et al., 2014),

- And high expense (Janne d'Othée, Langdon, Bell, & Bettmann, 2006), and

Providing expert training comes at a steep cost, both timely and financially, and the medical system has been looking at ways to lessen the stress it causes. Many specialties have turned to new technologies, such as computer simulation, in order to supplant some of the drawbacks of traditional methods. Simulation of invasive procedures has gained popularity in medical education, advancing from primitive cadaveric dissection to modern 3-D modeling instruments equipped with genuine haptic feedback. With increasing use of computer simulation and subsequent development of the technology (Malone et al., 2010), it is getting cheaper to provide crucial training to medical students, however, computer-based training modules require extensive research to verify their genuine representation of medical procedures. Some specialties, such as neurosurgery, perform invasive procedures that require especially detailed and accurate representation in simulators, and, as a result, have lagged technologically behind other specialties (Spiotta & Schlenk, 2011).

Implementing new learning tools and simulators also introduces inquiries into developing efficient, validated protocols. Since simulators can provide an endless number of emulated patients and symptoms (Hoffman & Vu, 1997), education using this growing database should be verified and standardized for efficiency and effectiveness. The degree to which novices are exposed to various clinical cases can have an impact on how natural the learning environment is and how quickly material and skills can be internalized.

# 2 Simulation

## 2.1 Simulation Development

Simulation has been defined as the imitation of the operation of a real-world process or system over time (Perkins, 2007). The use of simulation as an educational tool is deeply engrained in history; in fact many primitive forms of simulation can be overlooked as such due to their contrasting simplicity over how simulation is recognized in present day. The military has been perhaps the most famous practical implementer of original simulation, recreating chess-like warfare scenarios in order to generate a risk/benefit analysis (Bradley, 2006; Perkins, 2007). Although military uses for simulation are the cornerstone for its progression, other fields have also taken advantage of the benefits of simulation for centuries.

In medicine, dissection of body organs and tissues, a form of simulation, was studied in sacrificed animals since the 3$^{rd}$ century and in human cadavers since the 13$^{th}$ century (Frati et al., 2006). It is these processes that have given rise to modern cadaveric dissections that are being used to educate not only gross-level anatomy, but also procedural skills for various medical specialists. Training of endovascular skills has been aided with the use of synthetic models, anesthetised animals and human cadavers (Neequaye et al., 2007)

Advancements in the modern military also brought developments in the field of simulation to closely linked fields, such as aviation. Military aviation has perhaps been the leader in simulation throughout the 20th century. During World War II, military training needs spurred the development of simulation modules that would eventually become the highly central and mature virtual reality training suites that are used to train current pilots (Rosen, 2008). Although these new systems are increasingly expensive, they prove to ultimately be cost-effective (Strachan, 2000).

It is clear the industries that involve a high amount of risk, such as the military and aviation, are the industries that are pioneers in the field of simulation (Ziv, Small, & Wolpe, 2000) due to its increasing value. Other fields have taken notice and have used simulation for planning, risk reduction and control (Ziv et al., 2000) - transportation, legal proceedings, professional sports, homicide investigation training, and construction (Ziv et al., 2000).

The medical field, which includes a high amount of risk, has been stimulated into incorporating modern simulation methods into training due to advances in medical care, shifts in tolerance towards error and injury reduction (Ziv et al., 2000) and progression towards cost-reducing methods.

## 2.2 Types of Simulation

A variety of forms of simulation are used for training purposes in medicine. The simplest of methods utilize manikins and cadaveric specimens for psychomotor skill and basic cognitive education (Ziv et al., 2000). Manikins, for example, are established in First Aid training as a low-cost, realistic solution to providing effective skill acquisition in life support manoeuvres. Cadaveric models are another simple method of simulation, commonly used to teach anatomy and various clinical procedures, such as breast examinations and anaesthesia administration (Ziv et al., 2000). However, these models can be expensive for the amount of use they provide, can be limited in availability and vary in quality based on fixation techniques used (Ziv et al., 2000).

Standardized patients are also a form of simulation, however, unlike models that teach technical skills, they are used to train communication skills with patients. These s have become some of the most widely studied methods of simulation in medicine (Barrows, 1993) and have become a necessary component of medical curricula.

With the technology that is being developed today, it is possible to train skills in virtual environments. Virtual reality (VR) systems allow trainees to interact with a 3D digital world in a human-computer interface (Gorman, Meier, & Krummel, 1999). Through the use of hand tracking devices, motion suits, and haptic feedback mechanisms, VR allows for complete immersion into the environment, facilitating the acquisition of skills (Greenleaf, 1996). With new technologies being developed continuously, this method is become more immersive and clinically relevant as a training tool.

A category of computer-driven task/procedural trainers is also growing rapidly (Ziv et al., 2000). These systems use realistic, interactive cues, such as hapsis and auodiovisual cues, to guide the user through a variety of computer-driven clinical scenarios (Perkins, 2007). A famous example of this form of simulation is the Harvey Cardiology Patient Simulator, which presents cardiovascular training scenarios, has shown to improve efficacy over traditional methods of teaching alone (Issenberg et al., 1999).

## 2.3 Benefits of Simulation

The benefits of simulation can sometimes be difficult to prove with the variety of applications that are available (Gaba, 2004). One of the reasons behind this challenge is some aspects of simulation rely on long term cumulative synergies, applied in a consistent manner, to exhibit benefits (Gaba, 2004). However, there are still many strong supporting arguments.

Not only do trainees find that simulation is useful in achieving learning objectives, they find cross-training to benefit interspecialty collaboration and skill transfer (Nelson et al., 2014). Simulation Based Medical Education (SBME) also complements traditional training approaches, such as bedside teaching, problem-based learning and lectures (Ziv, Ben-David & Ziv, 2005). SBME provides opportunity to learn from mistakes through an error management system. This not only creates technical enrichment for mechanical skills learning, but complements the strive for excellence that is promoted in medicine (Ziv, Ben-David & Ziv, 2005).

Simulation training provides the opportunity to train mechanical skills on rare, but vital cases that the trainees may not otherwise see in their training, a condition that is viable in fields such as critical resuscitation (Smith et al., 2010). The difficulty of cases can also be graded in order to facilitate learning (Pellegrini, 2006; Spiotta et al., 2012) and can be taught complementary to apprenticeship experience.

A central component of simulation-based medical education is arguably error management (Ziv, Ben-David, & Ziv, 2005). Not only does simulation have implications in error analysis and error correction (Ziv et al., 2000), but it allows for learning from errors in a risk-free environment (Lopreiato & Sawyer, 2015). As a result, practicing high-risk procedures without psychological stress can benefit long term retention and transfer of skills (Kahol et al., 2010).

Simulation has also been shown to promote the development of decision-making skills and reflective learning and debriefing (Ziv et al., 2000), all of which are crucial components of professional maturity.

## 2.4 Limitation of Simulation

A simulator requires a significant initial expense that some facilities could not justify, especially if the audience and training modalities are limited (Ziv et al., 2000). As well, there is a need for technical and professional support in order to maintain the efficacy of the machine (Nelson et al., 2014).

Simulation equipment needs large studies with qualified professionals in order to validated as an appropriate teaching method.

## 2.5 Simulation of Endovascular Procedures

It has been shown that using virtual reality systems, computed tomography angiography, magnetic resonance angiography and 3-D imaging can be beneficial to familiarize the trainee with patient anatomy and facilitate surgical planning (Spiotta & Schlenk, 2011) in a variety of situations (Hoffman & Vu, 1997). A simulated surgical ecosystem can provide a zero-risk learning environment, which, through simplified procedures, can effectively establish skills in trainees – the more realistic the simulator, the more transferrable the skills (Spiotta et al., 2012).

# 3 Angiography

Cerebral angiography is the study of blood vessels of the brain and neck using an imagine technique, such as x-ray or CT. A catheter is guided under fluoroscopy, a contrast is injected, and vessel competency is assessed through rapid sequence films (Frizzel, 1998). Diagnostic angiographic images are obtained through digital subtraction images. The process of digital subtraction angiography, or DSA, involves taking a mask image of the relevant anatomy without contrast and subtracting from it the image of the anatomy with the contrast injected. This technique reveals important vascular detail without irrelevant extravascular anatomy (Cowling, 2006).

Early angiographical procedures were performed through surgical exposure of the cervical arteries, however, with development of new techniques (such as Seldinger), and tools, the transfemoral route, a puncture of the femoral artery, below the inguinal ligament, was introduced (Cowling, 2006). With the introduction of specialized tools, such as catheters and radiographic equipment, angiography assumed a vital role in diagnostic medicine (Cowling, 2006).

The boom of the use of angiography in Europe 1930, after the development of proper contrast formulas, did not migrate over to North American medical practice until much later, mostly due to the potential risks of cannulating the external carotid artery and dangers associated with contrasts used at that time (Cohen et al., 2013). Currently, angiography uses iodine-containing contrast mediums which only have minor side effects.

## 3.1 Aneurysms

Aneurysms are pathological dilations of the arterial wall that form around areas of high wear and tear, such as points of bifurcation in the Circle of Willis (Brisman, Song, & Newell, 2006). Figure 1 shows the common locations aneurysms are found.

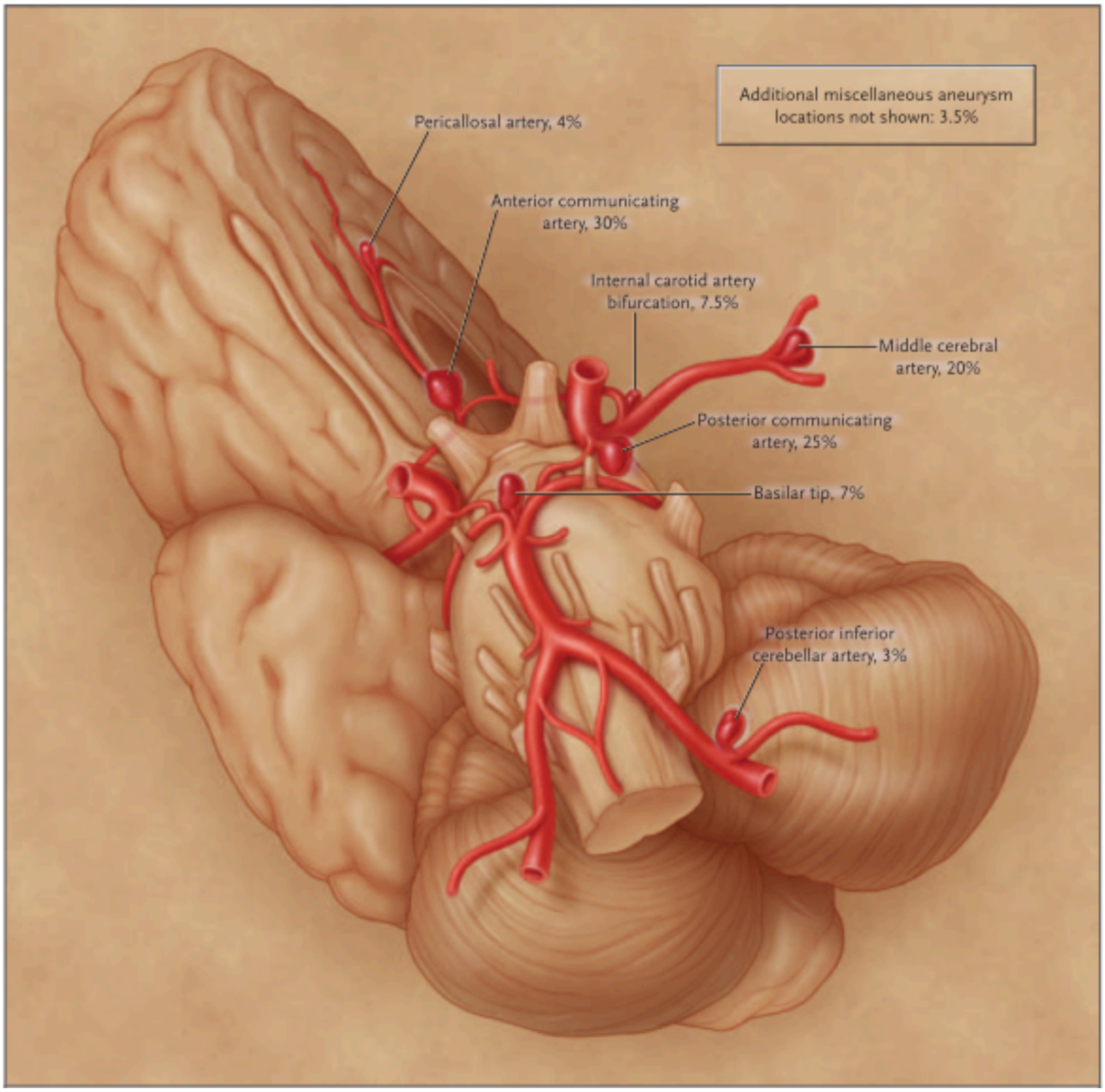



**Figure 1: Common locations of intracranial aneurysms**

“Reproduced with permission from (Brisman et al., 2006), Copyright Massachusetts Medical Society, **Appendix A**

### 3.1.1 Prevalence & Detection

The prevalence of intercranial aneurysms is about 1-5% of the adult population with about 1 in 10 000 haemorrhaging in the subarachnoid space (Ingall, Whisnant, Wiebers & O’Fallon, 1989; Wibers et al., 2003), Cerebral aneurysms often exist without any presentation which makes their diagnosis much more difficult. Aneurysms smaller than

1cm have a very low risk of rupture in patients without SAH history (Wiebers et al., 1998). It is estimated that 50-80% of all aneurysms won't rupture (Brisman et al., 2006) Symptoms other than rupture are unlikely, but when they do present they can cause nerve entrapment and ischemia, resulting in a symptomatic presentation (Friedman et al., 2001). Entrapments are most likely to happen around cranial nerves II (CN II) and III (CN III), resulting in loss of visual acuity (CN II), normal eye and eyelid movement (CNIII), and pupil constriction (CN III) (Friedman et al., 2001). However, these aneurysms were fairly large, mostly ranging between 5-8mm (Friedman et al., 2001).

If an acute haemorrhage has occurred, an aneurysm can produce a severe and sudden 'thunderclap' headache (Witham & Kaufmann, 2000). These warning headaches are followed by a subarachnoid haemorrhage (SAH) in 5% to 60% of patients (Jakobsson, 1996). Previous SAH lead to 11 times the chance of rupture (Wiebers et al., 1998), with 2-4% of hemorrhages bleeding again 24 hours after the initial episode and 15-20% bleeding within the first two weeks. SAH has a 30-day mortality rate of 45%, with 30% of survivors suffering from moderate-to-severe disability (Johnston, Selvin, & Gress, 1998). If these symptoms arise, a CT scan is done, which will show if there is bleeding. However, CT scan does not show the source of the bleed, and angiography of the region would need to be done (Brain Aneurysm Foundation).

### 3.1.2 Treatment

Diagnosis of aneurysms was only the first goal in the development of proper interventional techniques. Medical practice went through an array of techniques to treat aneurysms, from ligation of the ICA to forced embolization of blood inside the dome of the aneurysm (Cohen et al., 2013). A more direct approach of wrapping the aneurysm using muscle from the thigh in the 1930s developed into a dominant technique of clipping the neck of the aneurysm (Cohen et al., 2013). Presently, thanks to Guglielmi's development of platinum detachable coils in late 20th century, aneurysms can be treated without transcranial surgical approaches (Cohen et al., 2013). These endovascular treatments are found to be more effective at treating unruptured aneurysms than surgical clipping (Higashida et al., 2007)

## 3.2 Angiography Complications

Cerebral angiography has a low complication rate with only 0.5% (Willinsky et al., 2003) of patients suffering from any form of permanent damage post-operatively. Death is quite uncommon, having an incidence of 0.14%, and usually associate with a risk factor (Kaufmann et al., 2007). Infection rate is almost-nonexistent, with 0.1% of patients developing a local injection-site infection (Kelkar, Brett Fleming, Walters, & Harrigan, 2013).

## 3.3 Angiography risks

One of the risks behind the use of diagnostic angiography is patient radiation exposure. X-ray beams are absorbed by tissues either entirely or partially, providing contrast between tissues. The x-ray beams can create direct cellular damage, however, if exposure is low, this damage has potential to be repaired by repair mechanisms in the body (Hetault et al., 2015). If a threshold of radiation exposure is reached, clinical consequences, such as skin injury, may follow, correlating to the amount of exposure (Hetault et al., 2015).

# 4 Endovascular Training

Endovascular training typically consists of a 24- to 48-month, based heavily on clinical experience (Mitha, Almekhlafi, Janjua, Albuquerque, & McDougall, 2013). Early in the training process,

Cost of angiography suite procedures averaged at 690$/hour, (Janne d’Othée et al., 2006)

## 4.1 Endovascular Simulation

Endovascular simulators have gained popularity over the last 15 years and grown to be supplied by a variety of companies. VIST simulator from Mentico, has been tested in a variety of carotid stenting and interventional scenarios with varying results. VIST is always beneficial to novices learning the procedures (Dayal et al., 2004; Hsu et al., 2004; Berry, Lystig, Reznick, & Lönn, 2006), however it is not very helpful to experienced interventionalists (Dayal et al., 2004). Practicing on the simulator has not always helped with improving procedure time, with some showing progress (Patel et al., 2006) while others didn't (Berry et al., 2006), however, there seems to be consistency in improving fluoroscopy time (Berry et al., 2006). VIST has also been effective in improving the amount of contrast injected (Patel et al., 2006).

A very similar simulator, but one that contains more updated haptic feedback mechanisms, ANGIO Mentor from Simbionix, has been shown to be an effective tool for psychomotor skill learning in both cardiac stenting and diagnostic cerebral angiography simulation (Spiotta, Rasmussen, Masaryk, Benzel, & Schlenk, 2011). Work on the simulator has been shown to exhibit that residents perform diagnostic cerebral angiography with more erroneous actions than fellows, even though fellows saw improvement on the simulator with the residents (Spiotta et al., 2011). Practicing on the simulator has also been shown to reduce total procedure time and fluoroscopy time (Lee et al., 2009; Spiotta et al., 2011). The amount of contrast injected, however, has not been shown to significantly change with practice on the simulator (Lee et al., 2009)

Although both VIST and ANGIO Mentor have been proven to have face and construct validity, device specific differences still exist(Dawson, Meyer, Lee, & Pevec, 2007).

# 5 Methods

## 5.1 Participants

Participants were selected from three main eligible pools at the University of Western Ontario – the Clinical Anatomy program graduate students, neurosurgery residents, and radiology residents. These pools were used to establish homogeneity in overall vascular anatomy competence and relevance to the participants' fields of study. A total of 16 participants were recruited; 8 graduate students, 4 neurosurgery residents, and 4 radiology residents. The participants did not receive any compensation for this study.

## 5.2 Assessments

Participants were provided with a vascular anatomy e-learning module, for which they had free time, and were informed of a quiz that would take place immediately following the module. A 10-question, untimed, multiple choice vascular anatomy quiz was then administered and an 80% or higher grade point score was required in order to proceed with the rest of the study.

Upon completion of the anatomy tutorial and quiz, participants were asked to complete two Vandenberg and Kuse mental rotations tests (Vandenberg & Kuse, 1978) on the computer. They were provided with sample questions at the beginning of the test to help understand the task, and were subsequently given two tests of 12 questions each. The subjects were given 3 minutes to complete each test, after which the software automatically ended the test.

All anatomy testing material and the use of MRT tests were established by Dr. Ngan Nguyen.

## 5.3 Grouping

The study design consisted of two groups that received different cases to practice on before they were tested. Inclusion into groups was sorted based on date of acceptance into the study, with the first participant joining the first group, the second participant joining the second group, the third participant joining the first group and so on. The groups were also controlled to have the same number of graduate students and residents in each. This was done to control for any unforeseen biases that may be present in one of the participants academic backgrounds.

### 5.3.1 Alternating vs. Consistent

The two groups that participants were divided into were the alternating practice group and the consistent practice group. The alternating practice group received different cases to train with on odd and even sessions. On the odd sessions, alternating group participants performed diagnostic angiography on the left internal carotid artery (L-ICA). On the even sessions, the alternating group participants performed diagnostic angiography on the right posterior inferior cerebellar artery (R-PICA). In contrast, the consistent group always practiced diagnostic angiography on an aneurysm in the L-ICA. In every session, after practicing, all participants were tested on the diagnostic angiography of an aneurysm in the right middle cerebral artery (R-MCA). Therefore, all participants received the same amount of practice and were all tested on the same case. Refer to Figure 1 for visual representation of the group layout.

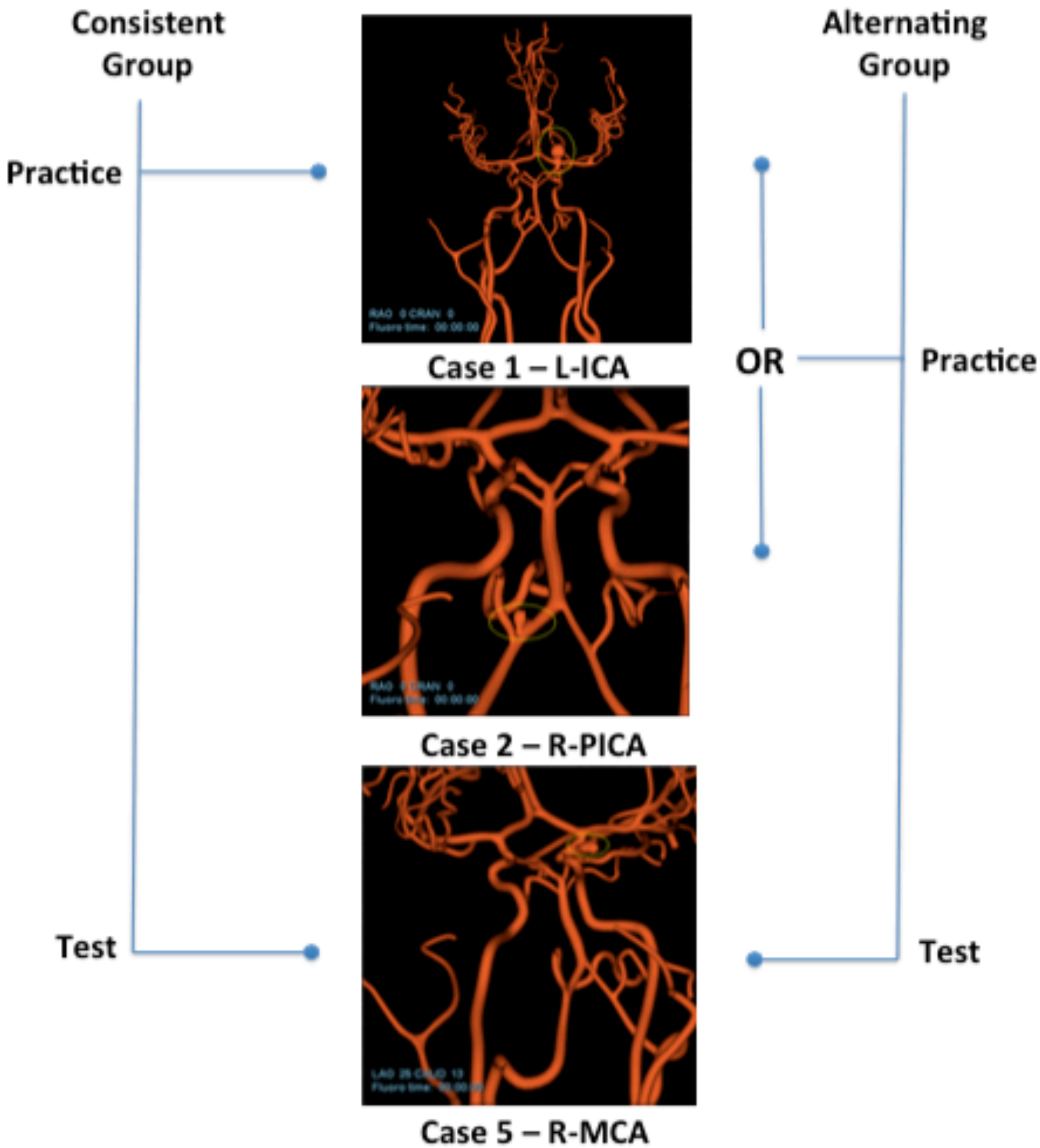



**Figure 2: Session layout for the alternating and consistent practice groups**

## 5.3.2 High MRT vs. low MRT

Subjects were assessed for visuospatial ability using the Mental Rotations Test. A score on a scale of 0-24 was received and individuals were assigned to a score group. Scores that fell into the top and bottom quartiles were a suggested criteria for identifying low and high visuospatial individuals (Wanzel et al., 2002), however, the power from this segregation would be too low, and an adapted formula was used. Instead of using quartiles, the bottom and top thirds were used as low and high visuospatial individuals. This provided enough power for statistical analysis, but also isolated the medium scoring group from the calculation. As a result, scores 0-9.5 were low MRT, 10-15 medium MRT, and 15.5+ were high MRT scores.

## 5.4 Sessions

Participants were allowed free time on the practice case, as long as they were following the provided instructions. Participants were also allowed to ask questions about the procedure at this time. Performance parameters were recorded by the simulator, but were not used in data collection in this study.

Immediately following the practice case, participants commenced the test case. A video was recorded from behind the participant, zoomed in on the fluoroscopy screen, during the participant's performance on the test case. The participants were not given any advice by the assessor during this period. The simulator logged all the data that was later retrieved for analysis.

When both the practice and test cases were completed, session performance was discussed with the participants. This was done to ensure that all participants had a uniform understanding of criteria used for assessing procedural competence, such as procedure time, fluoroscopy time, contrast injected and roadmaps used.

## 5.5 Simulator

The simulator is a long, portable hardware that contains a force feedback system to simulate the location of endovascular tools (Figure 3). External instruments, such as guidewires and catheters (Figure 4), can be inserted into a simulated vascular system that is displayed on the fluoroscopy monitor. The simulator control panel at the centre of the device contains joysticks for patient table and fluoroscopic C-Arm manipulation, fluoroscopic zoom, and roadmap management.


**Figure 3 Simbionix ANGIO Mentor simulator with a visible control panel**

Catheter and guidewire can be inserted into the force feedback capable system within the encolsure. The endovascular tools can be seen in Figure 4.

**Figure 4 Catheter (left) and guidewire (right) running through the catheter**

Two displays were used to provide the trainee with patient, tool and fluoroscopic information. The computer interpreted all data from the simulation console and displayed patient table, tools, injections, C-Arm positions and patient files on the built in screen and fluoroscopic images and vitals on the added monitor (Figure 5).

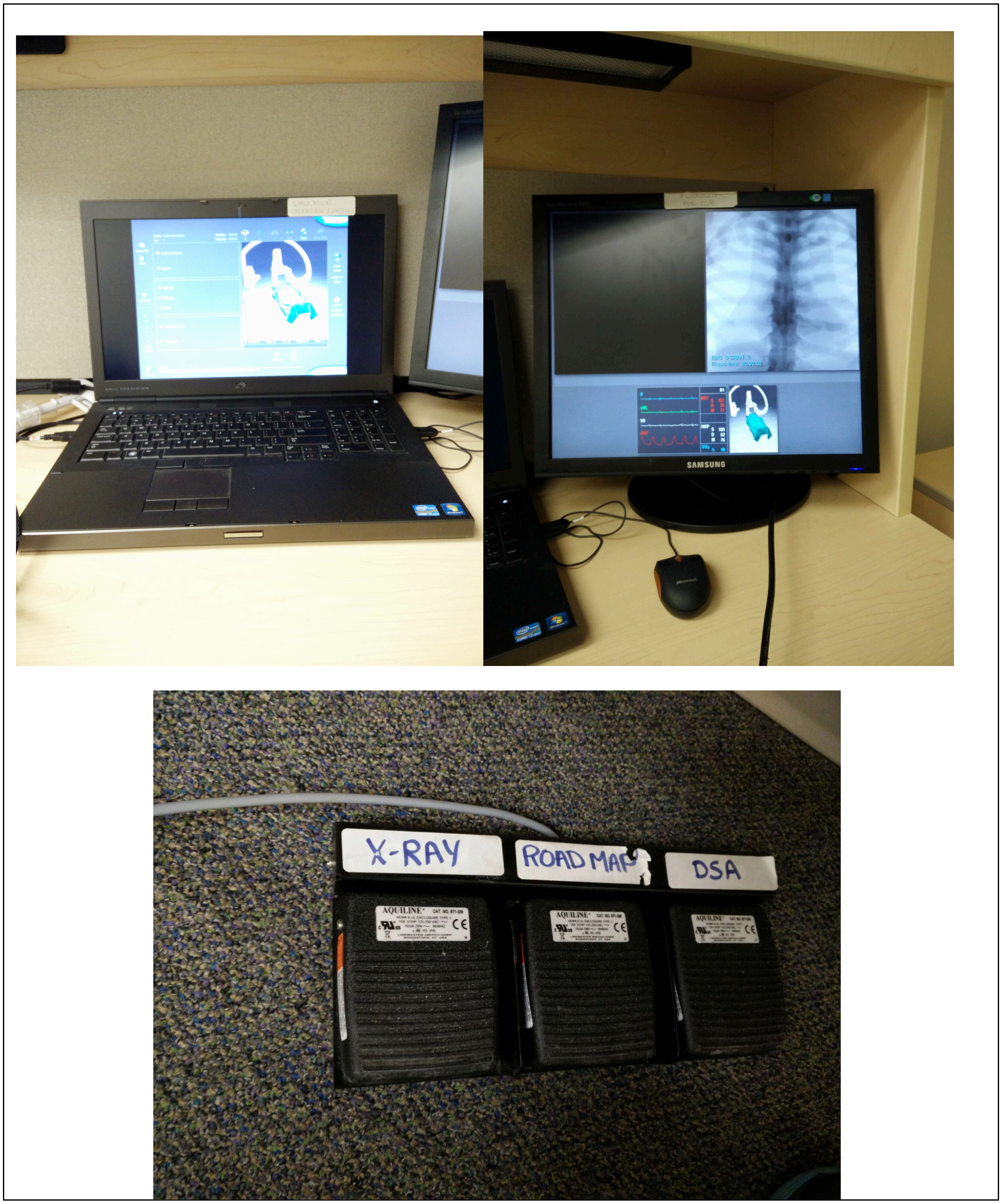



**Figure 5: Computer with main display (left) and fluoroscopic monitor (right) and pedals for fluoroscopy, roadmaps and DSA (bottom)**

Under the table, 3 pedals were available for x-raying, creating roadmaps and performing digital subtraction angiography (DSA)**(Figure 5)**. An example of procedural setup can be seen in Figure 6.

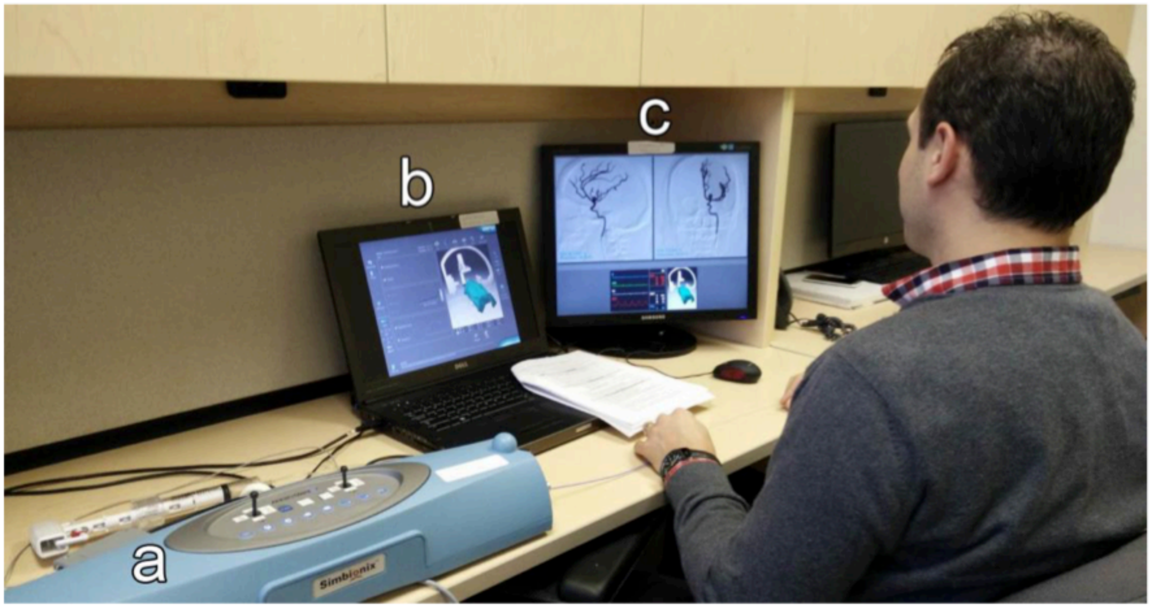



**Figure 6: A participant completes a practice scenario using the simulation console (A), main patient screen (B), fluoroscopy screen (C), and pedals (not pictured).**

# 6 Results

Participants were encouraged to come in once a week, however, since some of the participants were medical residents, scheduling issues were inevitable. As a result, one of the participants was not able to complete enough sessions for data collection. A total of 15 data sets were collected from 15 participants - 8 clinical anatomy graduate students, 4 radiology residents, and 3 neurosurgery residents.

## 6.1 Anatomy Assessment

All subjects successfully completed the anatomy assessment, scoring at least 80% on the required multiple-choice questions.

## 6.2 Total Procedure Time

### 6.2.1 Overall Performance

A significant decrease in total procedure time was observed from the initial session to the 8th session in all groups. A two-way repeated measures ANOVA revealed a significant decrease ($p<0.05$) in the time it took to complete the procedure, averaging from 1071 seconds on the first session to 272 seconds on the 8th session. An overview of the total procedure times can be seen in Table 1 and a graph of average performance can be observed in Figure 6. Full statistical analysis can be found in **Error! Reference source not found.**.

| **Total Procedure Time in Seconds** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Group | Participant | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| alt | 1 | 840 | 708 | 390 | 296 | 277 | 227 | 313 | 276 |
| alt | 2 | 1031 | 551 | 559 | 771 | 314 | 427 | 318 | 300 |
| sim | 3 | 1213 | 605 | 384 | 302 | 331 | 244 | 225 | 164 |
| sim | 4 | 1206 | 687 | 519 | 1349 | 522 | 514 | 404 | 603 |
| sim | 5 | 937 | 723 | 742 | 219 | 144 | 324 | 345 | 360 |
| alt | 6 | 826 | 327 | 384 | 202 | 290 | 191 | 208 | 232 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| sim | 7 | 1345 | 401 | 408 | 395 | 317 | 659 | 311 | 206 |
| alt | 8 | 1615 | 1094 | 571 | 330 | 411 | 260 | 352 | 263 |
| sim | 9 | 1168 | 662 | 1412 | 398 | 313 | 286 | 608 | |
| sim | 10 | 426 | 404 | 338 | 244 | 219 | 289 | 152 | 176 |
| alt | 11 | 1532 | 946 | 731 | 341 | 258 | 201 | 550 | 179 |
| alt | 12 | 1540 | 803 | 1140 | 1029 | 466 | 435 | 396 | 237 |
| alt | 13 | 1278 | 448 | 317 | 592 | | | | |
| sim | 14 | 904 | 416 | 344 | 273 | 450 | 257 | 245 | 290 |
| sim | 15 | 206 | 439 | 230 | 179 | 193 | 183 | 191 | 260 |

**Table 1: Total procedure time for all participants across all sessions**

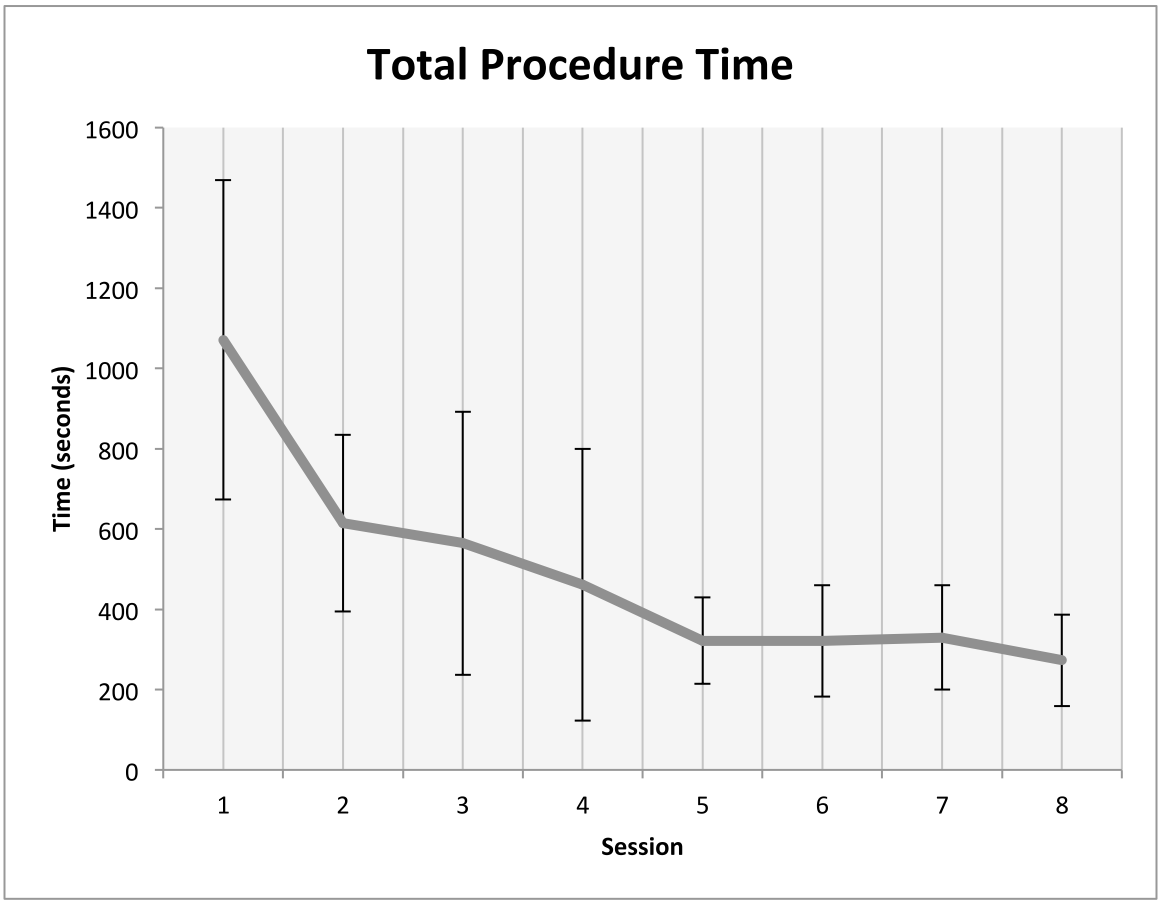



**Figure 6: Total procedure time for all participants over 8 sessions.**

### 6.2.2 Intersession Comparison

Pairwise comparisons revealed a statistical difference between sessions 1 and 5 ($p = 0.026$), 1 and 6 ($p = 0.018$), and 1 and 7 ($p = 0.028$). However, no significant differences were found between sessions 5, 6, 7, and 8. This could indicate that a plateau effect for procedure time may set in after the 4th training session in a generalized training protocol.

### 6.2.3 Alternating vs. Consistent Training

Although all individuals improved in procedure time, there was no statistical significance found between the alternating and the consistent training groups ($p = 0.718$) when no other factors were considered. The current group numbers were too low for the observed variance, and thus resulted in low power ($\pi = 0.061$). Performance of the alternating and simple training groups can be seen in Figure 7. Full statistical analysis can be found in **Error! Reference source not found.**.

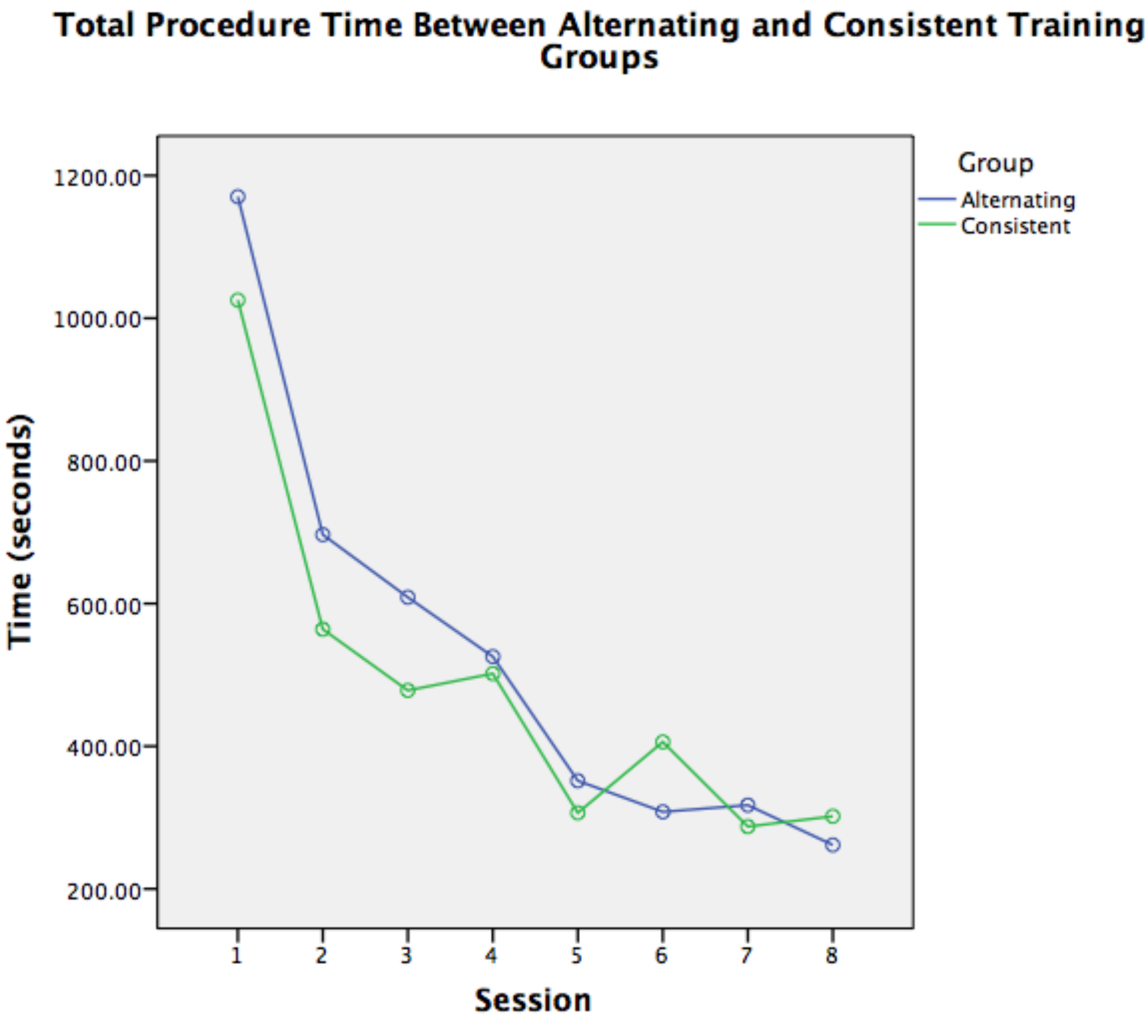



**Figure 7: Total procedure time between alternating and consistent training groups**

## 6.3 Total Fluoroscopy Time

### 6.3.1 Overall Performance

A two-way repeated measures ANOVA was completed and revealed a very significant ($p = 0.01$) decrease in fluoroscopy time from the first session to the 8th session. The average amount of fluoroscopy that was used reduced from 779 seconds to 156 seconds. The improved time on the last session was only 19.96% of the first sessions, marking a 5-fold improvement in the amount of fluoroscopy used and the amount of radiation the patient would potentially be exposed to. An overview of all fluoroscopy times can be seen in Table 2: Total fluoroscopy time of all individuals across all sessions**Error! Reference source not found.**.

| Total Fluoroscopy Time in Seconds | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Group | Participant | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| alt | 1 | 608 | 494 | 200 | 189 | 178 | 131 | 231 | 129 |
| alt | 2 | 878 | 431 | 346 | 636 | 242 | 378 | 245 | 201 |
| sim | 3 | 1020 | 537 | 281 | 209 | 266 | 205 | 184 | 113 |
| sim | 4 | 973 | 478 | 368 | 1160 | 439 | 471 | 305 | 436 |
| sim | 5 | 717 | 584 | 673 | 171 | 108 | 250 | 195 | 249 |
| alt | 6 | 710 | 168 | 204 | 143 | 245 | 102 | 97 | 109 |
| sim | 7 | 1193 | 310 | 333 | 352 | 274 | 572 | 219 | 138 |
| alt | 8 | 1196 | 928 | 436 | 224 | 209 | 197 | 203 | 113 |
| sim | 9 | 440 | 388 | 310 | 242 | 198 | 182 | 444 | |
| sim | 10 | 230 | 294 | 289 | 139 | 164 | 261 | 65 | 54 |
| alt | 11 | 1009 | 612 | 454 | 194 | 72 | 59 | 169 | 14 |
| alt | 12 | 1218 | 571 | 946 | 823 | 373 | 268 | 258 | 106 |
| alt | 13 | 883 | 306 | 232 | 396 | | | | |
| sim | 14 | 444 | 245 | 179 | 177 | 207 | 147 | 144 | 159 |
| sim | 15 | 164 | 338 | 182 | 134 | 143 | 122 | 146 | 200 |

**Table 2: Total fluoroscopy time of all individuals across all sessions**

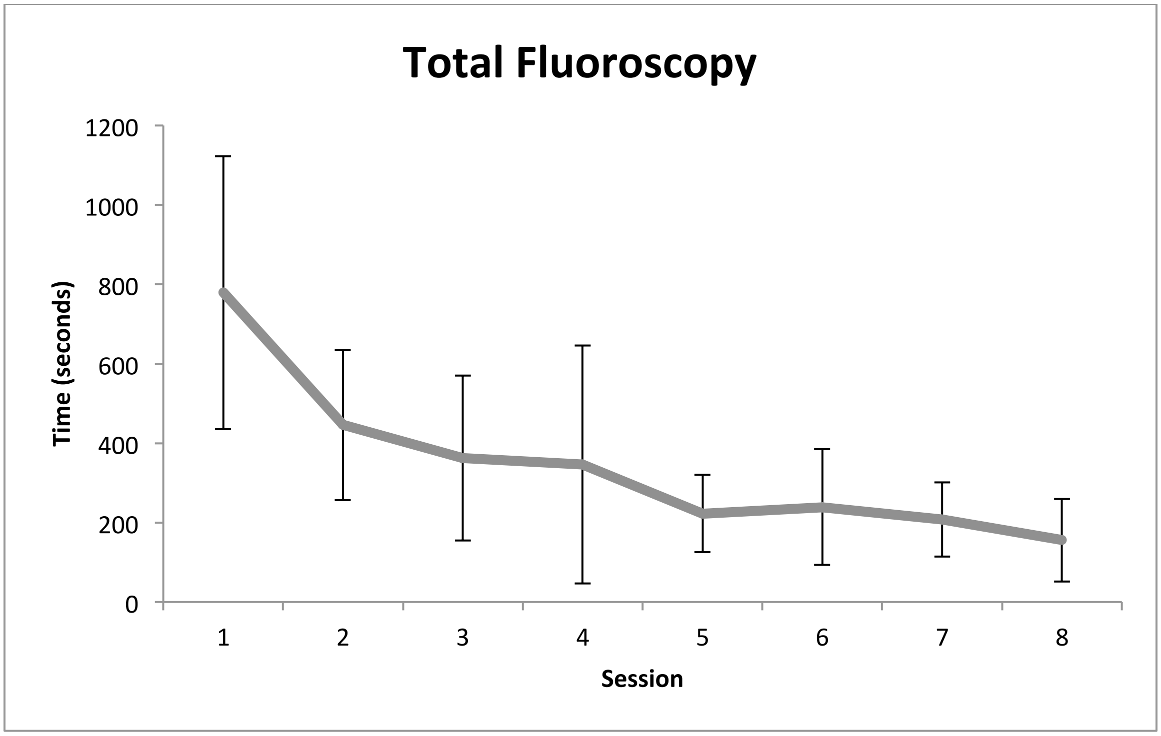



**Figure 8: Average total fluoroscopy time across all sessions**

### 6.3.2 Intersession Comparison

A pairwise comparison showed a significant correlation ($p<0.05$) between sessions 1 and 6, 1 and 7, and 1 and 8.

### 6.3.3 Alternating vs. Consistent Training

Upon comparing alternating and consistent training groups, it was found that there was no significant difference ($p=0.984$) between the two groups in total fluoroscopy time. A two-way repeated measures ANOVA revealed that the power was too low ($\pi= 0.05$) with the amount of variance that the data contained. Performance of the alternating and consistent training groups can be seen in the Figure 9. Full statistical analysis can be found in **Error! Reference source not found.**.

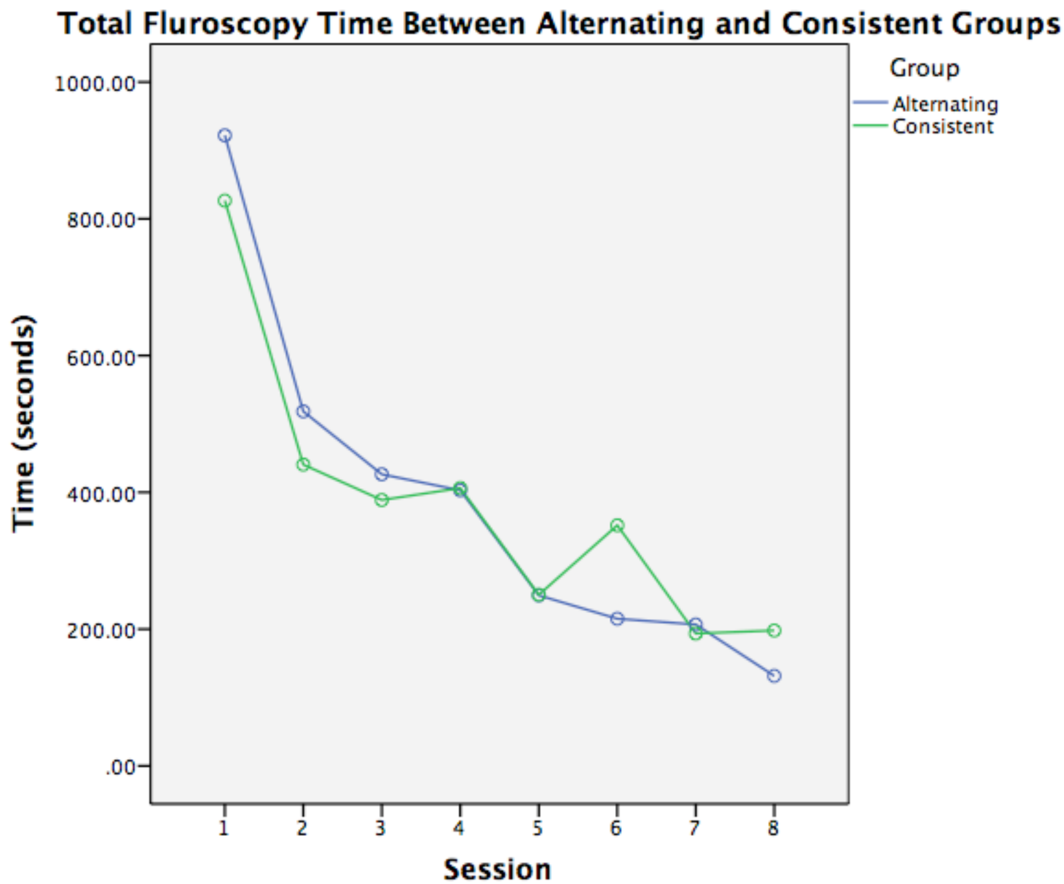



**Figure 9: Total fluoroscopy time between alternating and consistent groups across all sessions**

## 6.3.4 Total Procedure Time and Fluoroscopy Correlation

A comparison between the procedure time and fluoroscopy time was made and a strong correlation was found between them ($p<0.05$, $r=0.928$). A scatterplot representing their relationship can be found in Figure 10. This association was expected, but the strength of the relationship creates an interesting insight into predicting fluoroscopy times based on procedure times. Full statistical analysis can be found in **Error! Reference source not found.**.

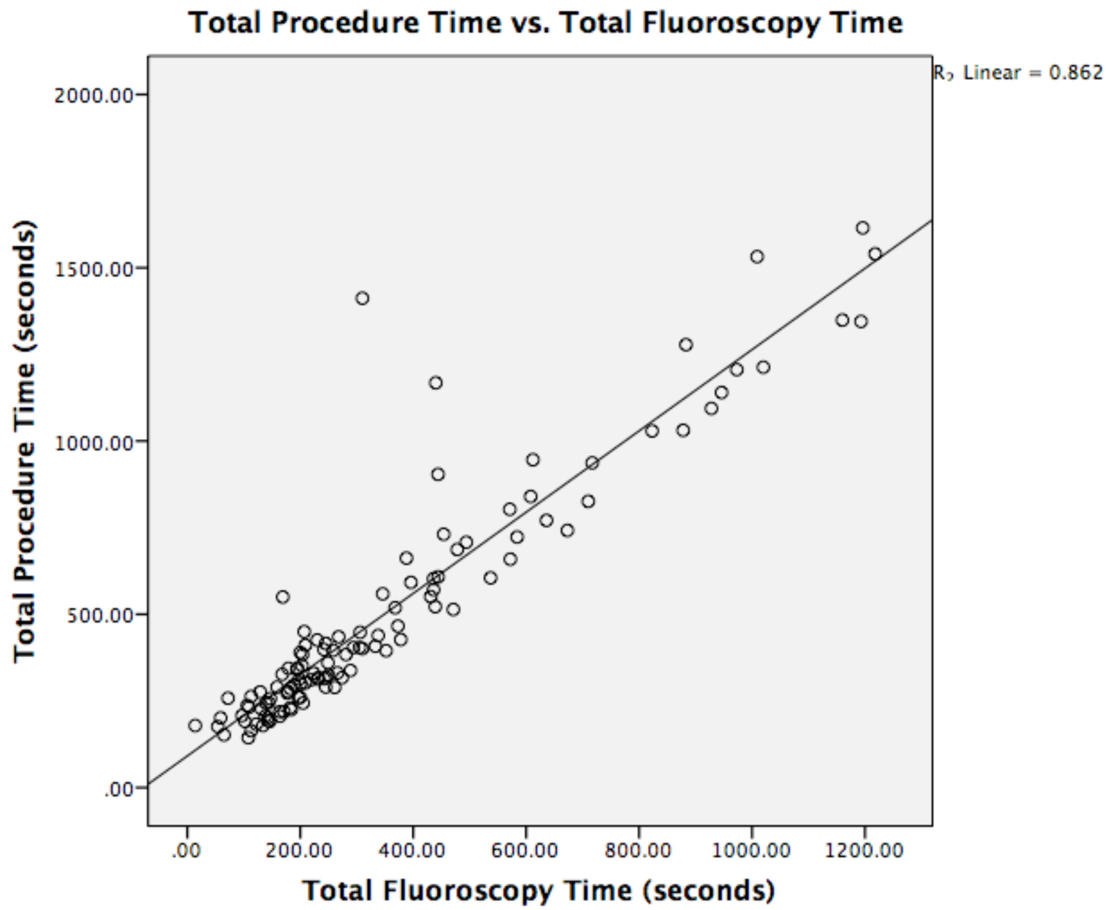



**Figure 10: Correlation between total procedure time and total fluoroscopy time**

## 6.4 Total Contrast Injected

### 6.4.1 Overall Performance

Over the 8 sessions, no significant difference in performance was seen (p=0.17). The mean amount of contrast injected in a session reduced from 75.3 mL on the first session to 38.8 mL on the 8th session, however, these values were not significantly different. Table 3 represents the contrast injection values for every participant at every session. The average contrast values for every session can be seen in Figure 11. Full statistical analysis can be found in **Error! Reference source not found.**

| Total Contrast Injected | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Group | Participant | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| alt | 1 | 40 | 48 | 40 | 40 | 32 | 56 | 32 | 32 |
| alt | 2 | 56 | 40 | 72 | 48 | 32 | 56 | 48 | 40 |
| sim | 3 | 56 | 24 | 32 | 32 | 48 | 32 | 32 | 48 |
| sim | 4 | 56 | 48 | 80 | 104 | 40 | 32 | 64 | 64 |
| sim | 5 | 88 | 32 | 32 | 24 | 24 | 48 | 64 | 32 |
| alt | 6 | 48 | 56 | 48 | 32 | 32 | 32 | 32 | 32 |
| sim | 7 | 40 | 32 | 32 | 32 | 32 | 48 | 40 | 32 |
| alt | 8 | 80 | 32 | 32 | 32 | 64 | 32 | 32 | 32 |
| sim | 9 | 136 | 248 | 184 | 160 | 104 | 40 | 48 | |
| sim | 10 | 48 | 48 | 32 | 32 | 48 | 32 | 32 | 40 |
| alt | 11 | 184 | 56 | 64 | 32 | 48 | 32 | 88 | 24 |
| alt | 12 | 96 | 48 | 40 | 48 | 32 | 24 | 48 | 32 |
| alt | 13 | 56 | 48 | 56 | 48 | | | | |
| sim | 14 | 80 | 24 | 32 | 40 | 56 | 40 | 40 | 48 |
| sim | 15 | 72 | 80 | 40 | 24 | 24 | 24 | 40 | 48 |

**Table 3: Total contrast injected of all individuals across all sessions**

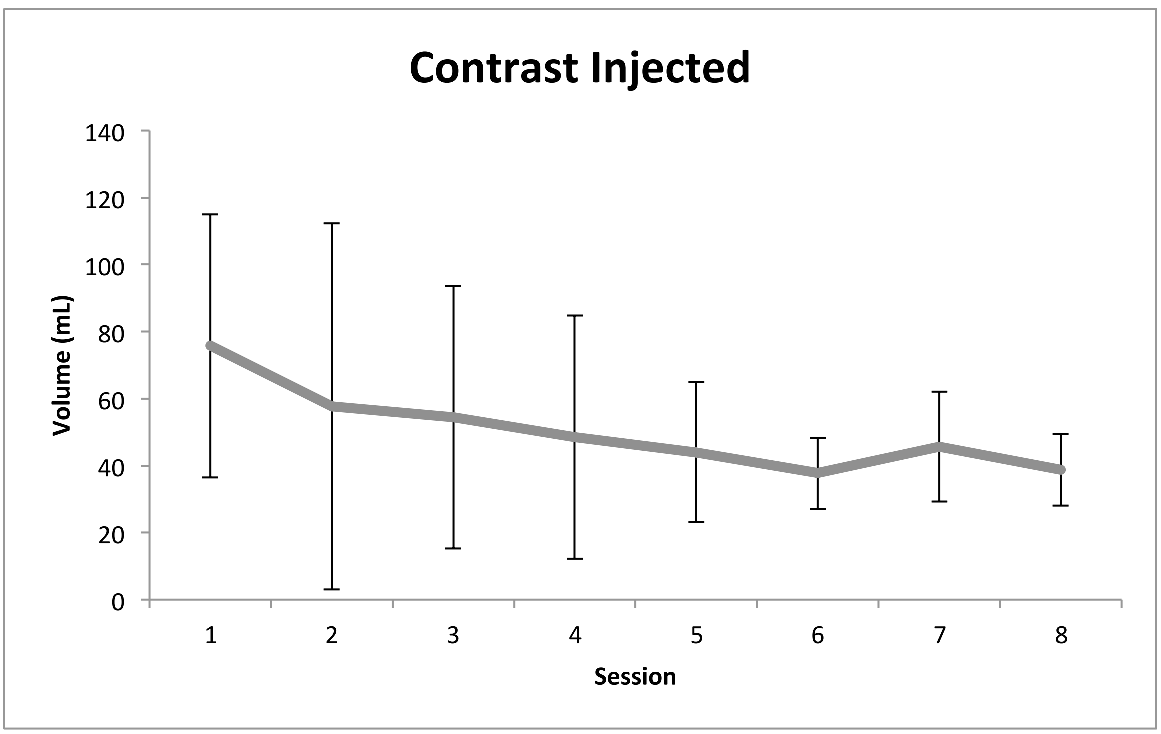



**Figure 11: Average amount of contrast injected across all sessions**

### 6.4.2 Intersession Comparison

Pairwise comparisons showed that there were no statistical differences ($p>0.05$) between sessions. Sessions 1 and 2 were not statistically different from each other, but had better significance ($p=0.08$) than the other intersession comparisons. This data may be showing only an initial learning boost of contrast management from the first session to the second, which is not helpful in subsequent sessions.

The data also exhibited a fair amount of kurtosis and this was not normally distributed, unlike total procedure time and total fluoroscopy time.

### 6.4.3 Alternating vs. Consistent Training

There was no significant difference found between the alternating and consistent training groups ($p=0.378$). The observed power $\pi=0.125$) was too low to be sensitive enough to detect change in performance between the groups. At the variance that was recorded between the groups, a higher number of participants were needed. Figure 12 shows the relationship between the alternating and consistent training groups. Full statistical analysis is available in **Error! Reference source not found.**.

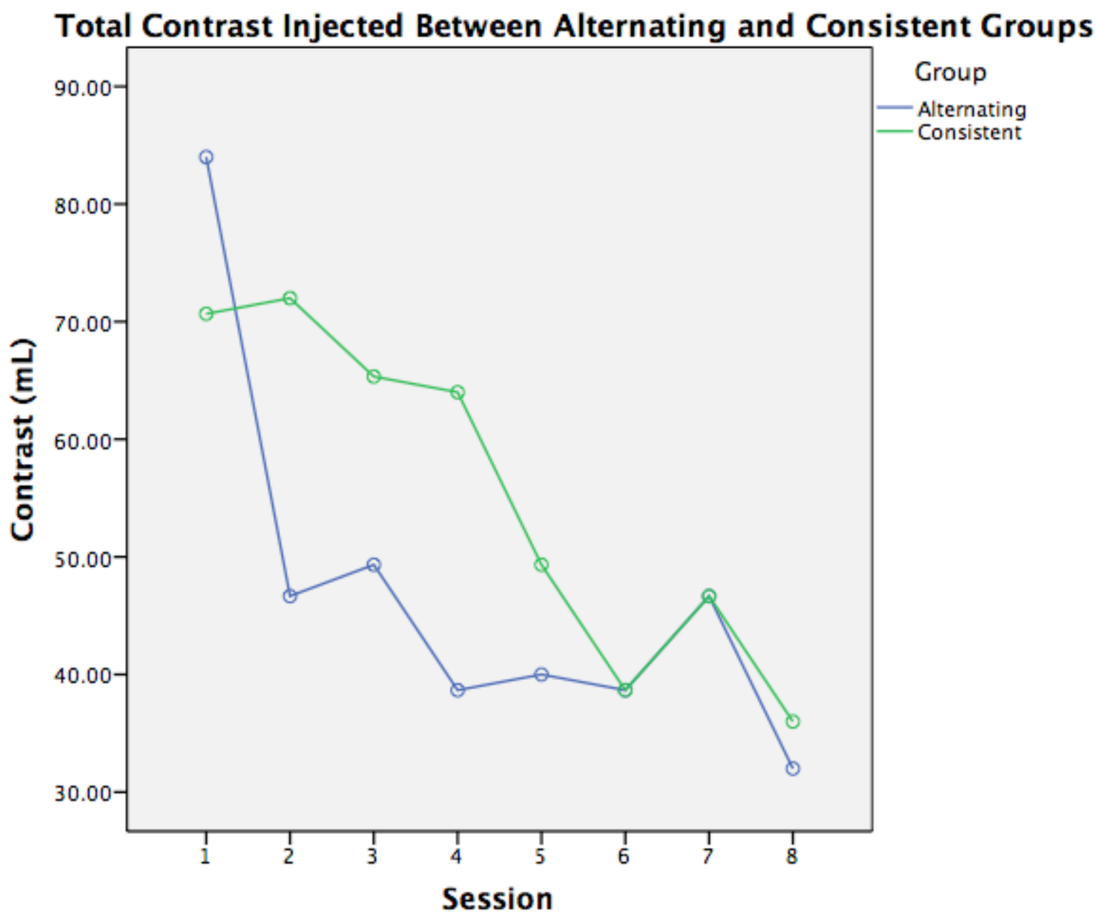



**Figure 12: Total contrast injected between alternating and consistent groups across all sessions**

### 6.4.4 Total Contrast Injected Correlations

It was found that there was no correlation between total contrast injected and procedure time. Total contrast injected had a correlation of 0.481 ($p<0.01$) with total procedure time and a correlation of 0.283 ($p<0.05$) with total fluoroscopy time. The relationship between total contrast injected and total procedure time can be seen in Figure 13and the relationship between total contrast time and total fluoroscopy time can be seen in Figure

14. Full statistical analysis can be found in **Error! Reference source not found.**.

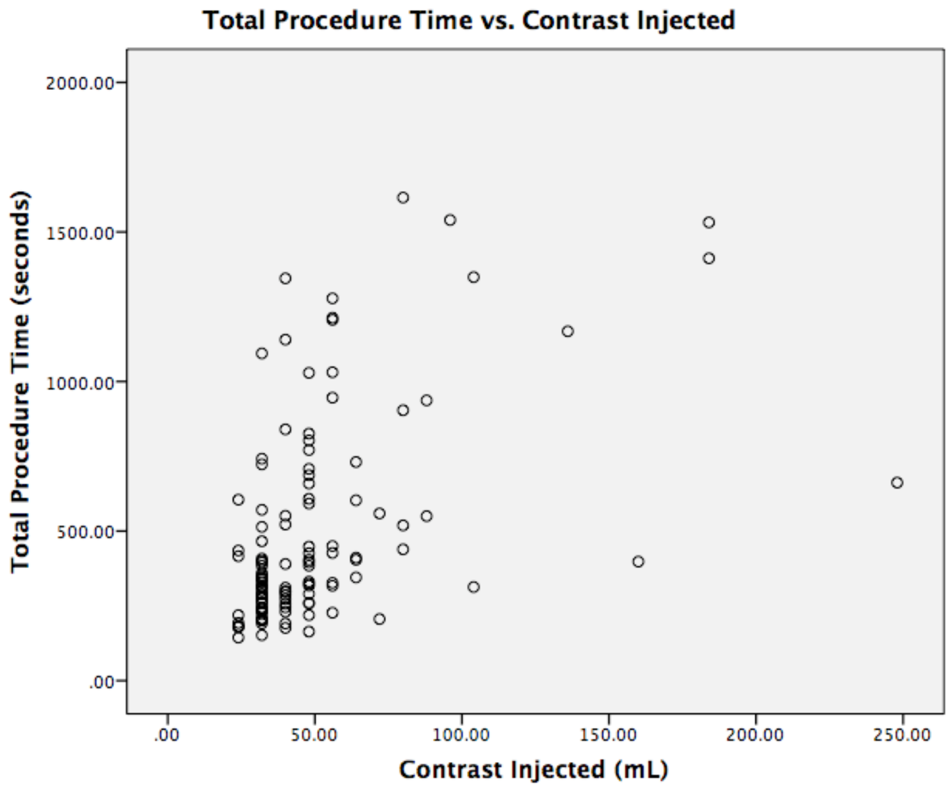



**Figure 13: Correlation between total procedure time and contrast injected**

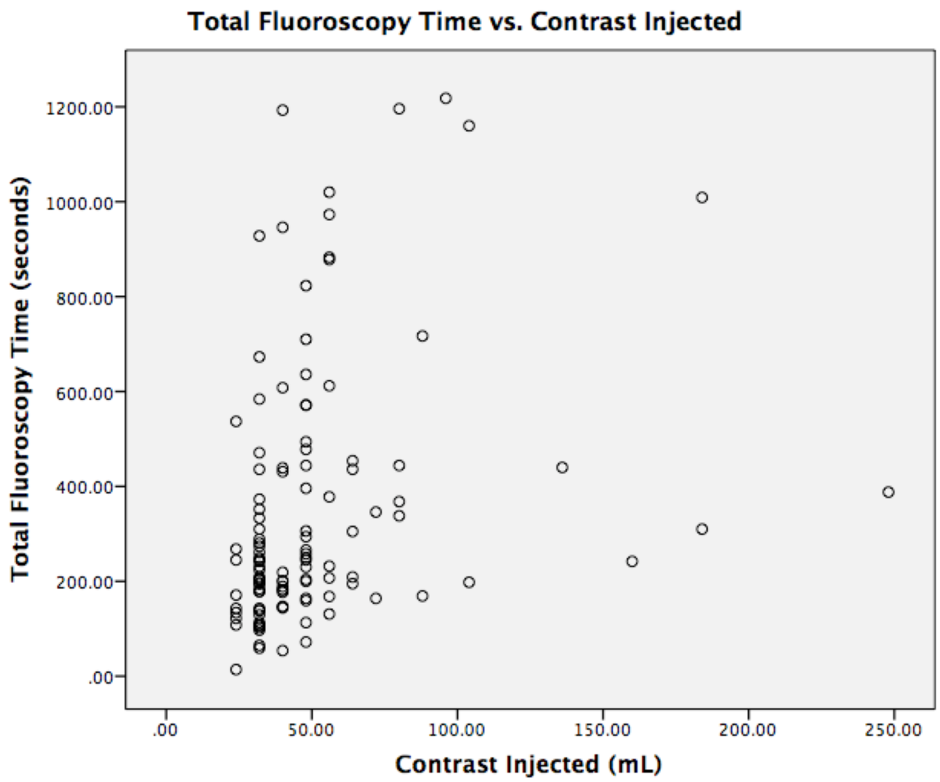



**Figure 14: Correlation between total fluoroscopy time and contrast injected**

## 6.5 Total Roadmaps

### 6.5.1 Overall Performance

A two-way repeated measures ANOVA revealed no statistical difference between sessions (p=0.096). The mean of the number of roadmaps decreased from 7.86 roadmaps in the first session to 5.08 roadmaps, however, these results had low power ($\pi$ =0.49). Table 4 outlines the number of roadmaps that were created by each participant by session, followed by Figure 15, which shows the combined performance of all groups between sessions. Full statistical analysis can be found in **Error! Reference source not found.**.

| Roadmaps Created | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Group | Participant | | | | | | | | |
| alt | 1 | 6 | 8 | 3 | 6 | 4 | 5 | 4 | 4 |
| alt | 2 | 7 | 5 | 10 | 7 | 4 | 10 | 7 | 5 |
| sim | 3 | 9 | 3 | 4 | 4 | 5 | 4 | 4 | 5 |
| sim | 4 | 6 | 11 | 11 | 15 | 6 | 4 | 8 | 11 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| sim | 5 | 9 | 4 | 4 | 3 | 3 | 5 | 6 | 4 |
| alt | 6 | 5 | 7 | 7 | 5 | 4 | 5 | 4 | 4 |
| sim | 7 | 6 | 4 | 4 | 4 | 4 | 8 | 7 | 4 |
| alt | 8 | 9 | 4 | 4 | 4 | 8 | 4 | 4 | 4 |
| sim | 9 | 4 | 10 | 9 | 6 | 4 | 4 | 6 | |
| sim | 10 | 7 | 10 | 4 | 4 | 5 | 5 | 4 | 5 |
| alt | 11 | 14 | 7 | 10 | 5 | 7 | 5 | 12 | 3 |
| alt | 12 | 15 | 6 | 5 | 4 | 4 | 3 | 5 | 4 |
| alt | 13 | 5 | 6 | 6 | 6 | | | | |
| sim | 14 | 8 | 3 | 4 | 5 | 7 | 6 | 5 | 6 |
| sim | 15 | | 13 | 4 | 3 | 2 | 3 | 4 | 7 |

**Table 4: Number of roadmaps created by all participants across all sessions**

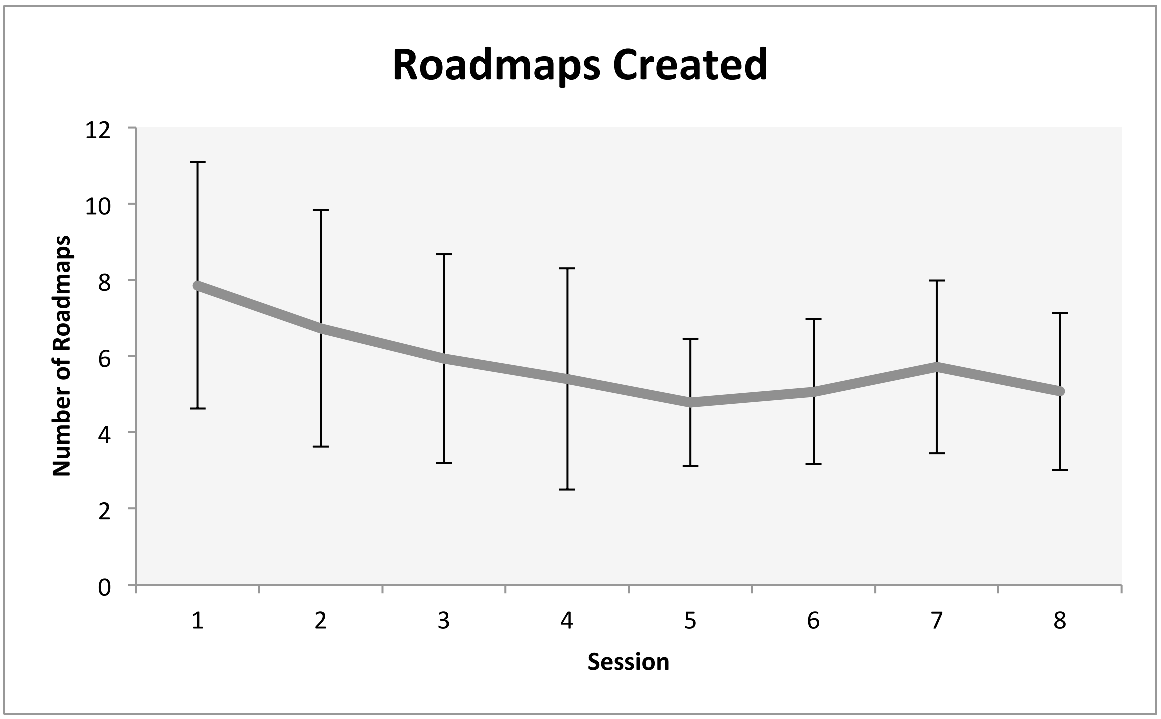



**Figure 15: Average number of roadmaps created at every session**

## 6.5.2 Intersession Comparison

Pairwise comparisons between individual sessions revealed no significant differences. Full statistical analysis can be viewed in **Error! Reference source not found.**.

### 6.5.3 Alternating vs. Simple Training

A two-way repeated measures ANOVA was done and no significant differences ($p=0.742$) were found between the alternating and consistent training groups. The power ($\pi=0.059$) was too low to differentiate between changes in performance between groups. Figure 16 shows the relationship between the two groups. Full statistical analysis can be viewed in **Error! Reference source not found.**.

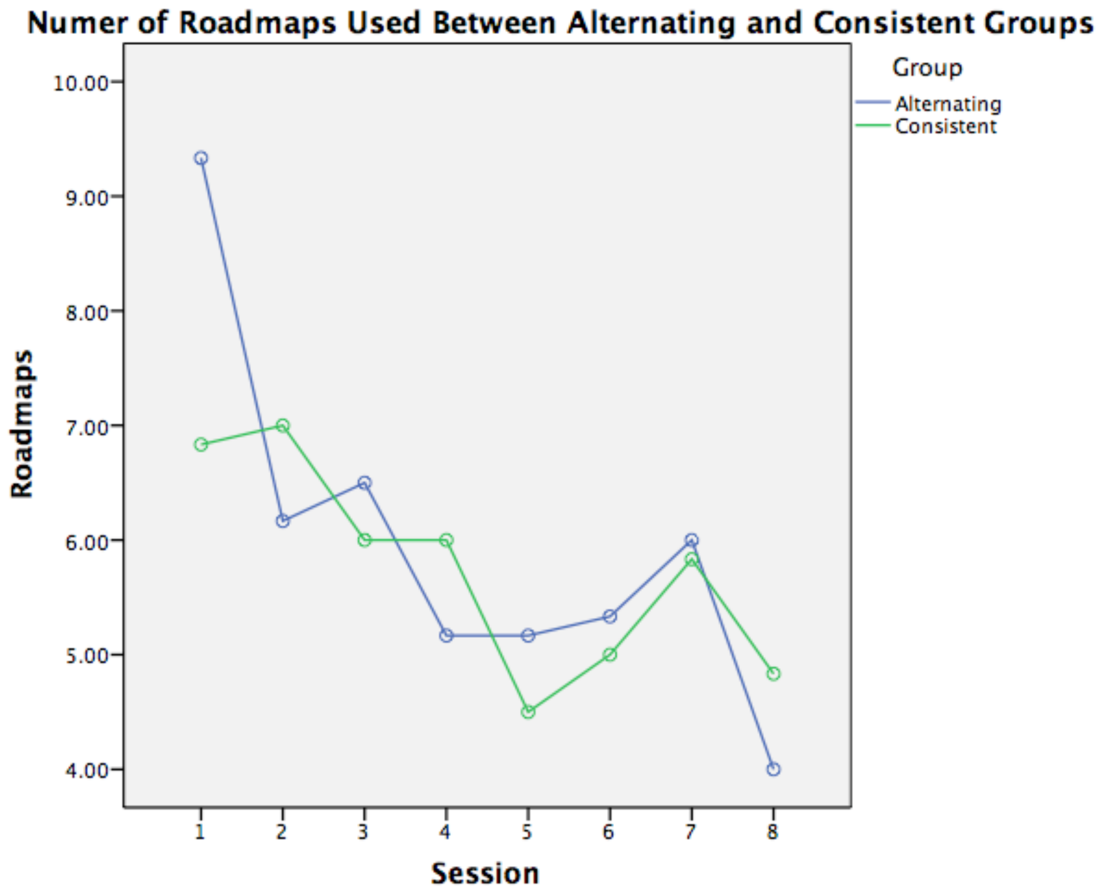



**Figure 16: Number of roadmaps created between alternating and consistent groups**

## 6.6 Low MRT vs. High MRT

Subjects that had a low MRT score and those that had a high MRT score were compared for differences in performance. A two-way repeated measures ANOVA revealed that the subjects with high MRT performed significantly better than subjects with low MRT (p =

0.007). This correlation could have accounted for lack of significant difference between alternating and consistent training groups since each group had different ratios of high MRT and low MRT individuals (

**Figure 17**). **Figure 18** shows the difference in performance between the different MRT groups.

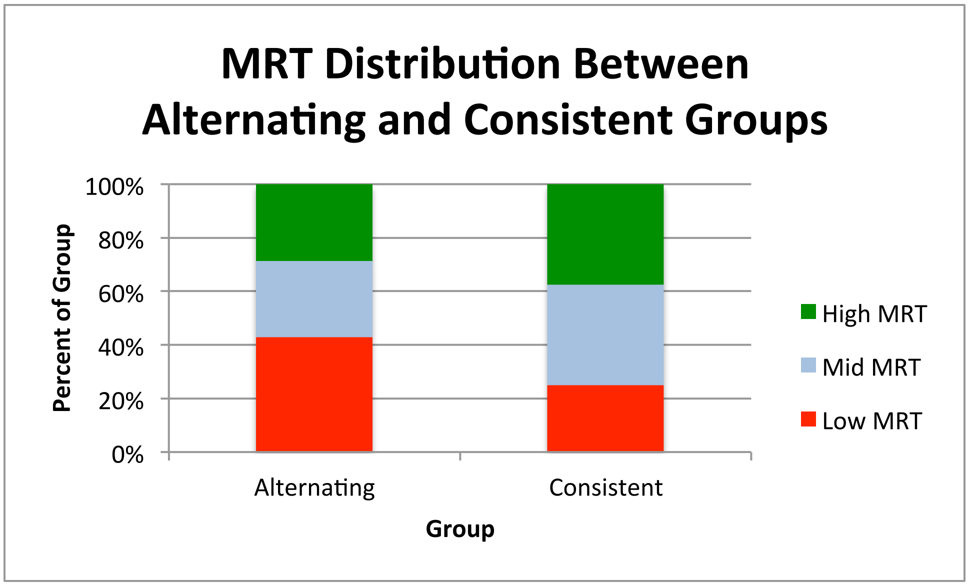



**Figure 17: Distribution of different MRT scores between training groups**

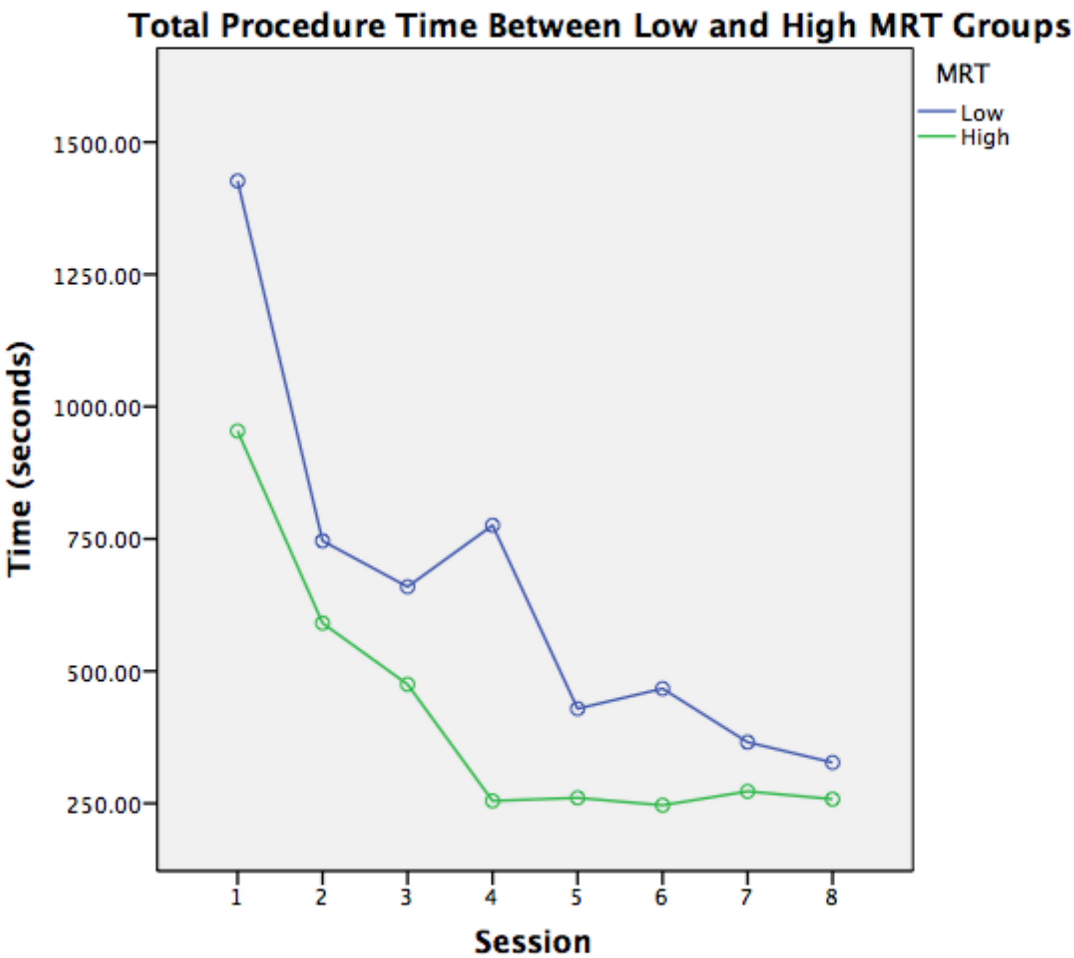



**Figure 18: Total procedure times between low and high MRT groups**

An independent variables t-test was done and no significance (p=0.533) was found between the alternating and consistent group MRT scores, however, the power was too low (π=0.12). The trend seems to indicate that there is a difference in performance between the MRT groups, however, this needs to be confirmed with a bigger sample size. The statistical analysis can be found in Appendix I.

# 7 Discussion

The purpose of this study was to analyze the relationship between training scenarios in cerebral angiography training. We aimed to establish a significant performance difference in individuals that received alternating cases of training on the endovascular simulator compared to the individuals that always practiced on the same case.

Contrary to our hypothesis, we found that the alternating training did not significantly improve the performance on the test scenario over the consistent training paradigm. I will address a variety of factors that may have played a role in diluting some of the data that we have collected.

## 7.1 Performance Across Metrics

On average, all participants significantly improved in total procedure time and fluoroscopy time. This was an expected result since other studies have also seen this trend using ANGIO Mentor (Lee et al., 2009; Spiotta et al., 2011) as well as other endovascular simulators (Berry et al., 2006; Patel et al., 2006). The total procedure time improvement also contradicts a Berry et al., (2006) study that showed that endovascular training did not significantly help with procedure time.

As participants learned to use fluoroscopy more effectively, they also affected their total procedure time. The correlation analysis exemplified that both procedure time and fluoroscopy were strongly correlated. This alludes to an important consideration: if this trend is also true in the angio suite, can procedure times be used to assess average fluoroscopy use by interventionalists and predict future fluoroscopy use?

Findings in procedure time and fluoroscopy time improvements indicate that the simulator is a good tool to train more efficient mechanical manipulation of tools. However, findings in the other two parameters, contrast and roadmaps, did not yield the same results.

No significant differences were found between total contrast injected and roadmaps created. Skewed normality distributions and low power, indicate that there were not enough participants tested in order to be able to detect a difference in these values. However, even though contrast and roadmaps could not be statistically improved in 8 sessions, the results were consistent with contrast usage data from other endovascular work (Lee et al., 2009).

A possible reason behind the lack of effects in contrast and roadmap use is that they encompass a separate domain than that of procedure and fluoroscopy time. Procedure and fluoroscopy seem to be heavily dependent on motor skills (aka. How quickly can I access a visualized vessel) whereas contrast and roadmaps use rely on mental anatomic schemas (aka. Can I visualize where the target vessels are).

## 7.2 Performance Between Sessions

Comparing the performance between sessions, we were able to see where the most significant learning takes place. When comparing total procedure times with the first session, the significance was found in sessions 6-8 (session 5 had moderate significance, $p=0.053$), indicating that 5-6 sessions are needed in order to ensure a significant amount of improvement has taken place. This can be an important metric for future studies assessing endovascular simulator performance. No significant differences were found between sessions 6, 7 and 8. This could indicate that a learning plateau is in effect beginning at the 6$^{th}$ session. Since significant effects were only seen in procedure time and fluoroscopy time, we can only speculate about the contrast and roadmap usage. Considering the mental anatomy schema model, it is possible that the roadmap and contrast usage would start improving around the plateau period, as spatial anatomical queries are being recognized.

## 7.3 Performance Between Alternating and Consistent Groups

We found no significant differences between the alternating and the consistent training groups on any of the criteria that were used to assess performance. The most likely hypothesis is that the number of participants was too low to detect a difference between the two groups. Assessing the amount of variance that is present at the first session, about 50 participants would be needed to provide the power for statistically significant results.

However, we can speculate on some visual differences that were observed on the graphs. On all the parameters that were observed (Figure 7, Figure 9, Figure 12, Figure 16), the alternating group always had worse performance on the first session. However, by the last session, all performance in the alternating group was exceeding that of the simple group, albeit non-significantly. With a higher number of participants, it would be interesting to observe if the pattern holds true for the rate of improvement in the alternating training group. With the data currently available, there is a trend towards alternating group improving more throughout the sessions than the consistent group.

Dividing the total procedure time performance into MRT groups provided significant results and insight into a potential confound at the group sizes we currently have. Individuals who scored in the high MRT group performed significantly better than individuals with a low MRT score. This indicated that if the alternating and consistent groups do not have the same ratio of low and high MRT scorers, the effect of different training paradigms may be clouded. In fact, the training groups did not have an equal distribution of MRT scores. Alternating training group consisted of 42% low MRT scorers and 29% high MRT scorers, compared to 25% low MRT and 38 high MRT scorers in the simple training group. If the MRT distributions were equal among the training groups, perhaps an effect would've been seen. A statistical analysis of the alternating and consistent training group MRT scores revealed no significant difference, however, with a low power, it is hard to conclude that the MRT was properly represented in both alternating and consistent groups. This signifies an important MRT criterion for accepting participants into a simulation based training paradigm.

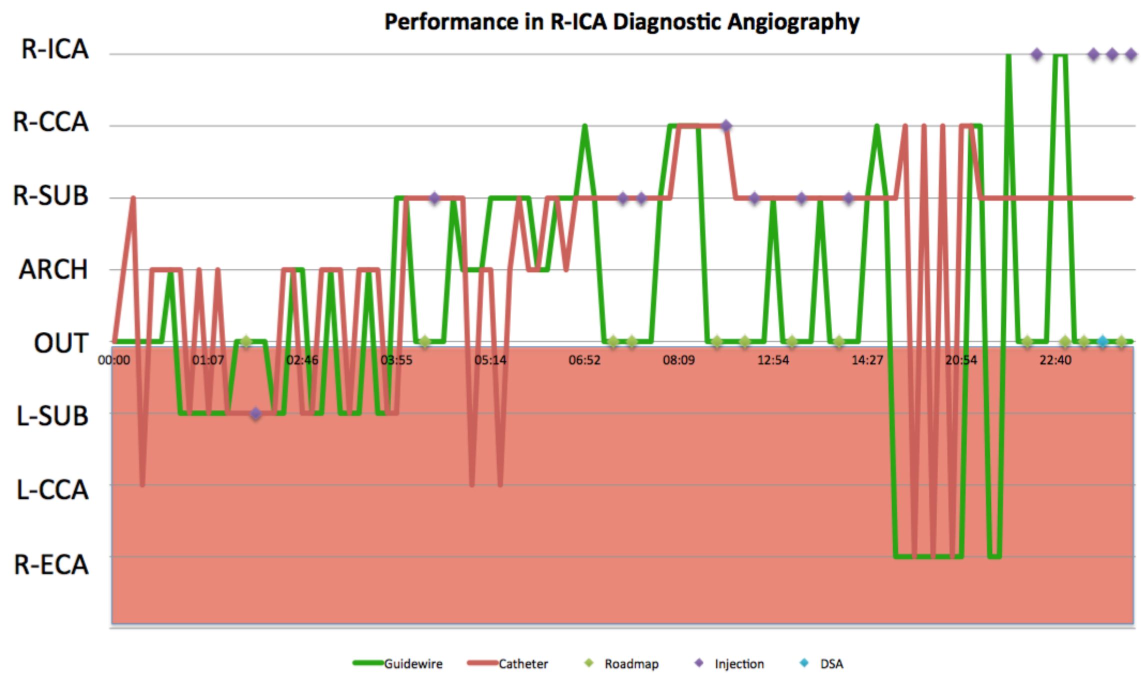
## 7.4 Limitations

One of the biggest limitations in the study was the small sample size. The amount of variance that was present across all performance metrics limited the analysis of the difference in training groups.

## 7.5 Future Direction

One of the biggest advantages of using simulation-based training is applying the controlled learning environment towards error reduction. Changes in tolerance of errors are creating an especially large requirement for assessing step-by-step performance during and after procedures. Simulators can provide specialists with vital quantitative information that could otherwise be missed in a clinical scenario.

ANGIO Mentor records a wide array of values that could be used to assess diverse forms of errors committed by trainees. Location data is an example of easily comprehensive




information that could be retroactively accessed to assess where spatial anatomical errors are being made.

Figure 19 represents a participant's tool location through the progression of the test case. These, with the use of a developed algorithm, automatically generated graphs can used to visually represent where a trainee is making mistakes. Y-values below the x-axis are representing vascular regions that would be incorrect to access in this particular scenario. For example, the participant in Figure 19 has mistakenly accessed the left subclavian artery with both the guidewire and catheter as they are attempting to find and access the brachiocephalic trunk at 1-4 minutes, the left common carotid artery briefly at 5 minutes, and the right external carotid artery at 16-20 minutes. This information can used to provide the learner with targeted training to resolve these spatial/anatomical errors.

**Figure 19: Anatomical Errors can be graphically represented to assess performance**

It would be wise to also compare performance of fellows who have previously received endovascular simulation training against those who haven't in an endovascular fellowship program. This would establish a correlation between simulator use and real clinical performance in the angio suite.

# 8 Conclusions

Endovascular simulators, such as the Simbionix ANGIO Mentor, have gained popularity due to their affordable application in clinical skill acquisition, risk free task training with realistic feedback systems, and error analysis prospects. We have shown that the ANGIO Mentor is an effective learning tool for reducing procedure and fluoroscopy times in novices, however, we did not satisfy our hypothesis in the benefits of alternating training. Further studies need to be completed to assess these conditions.

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# Appendices

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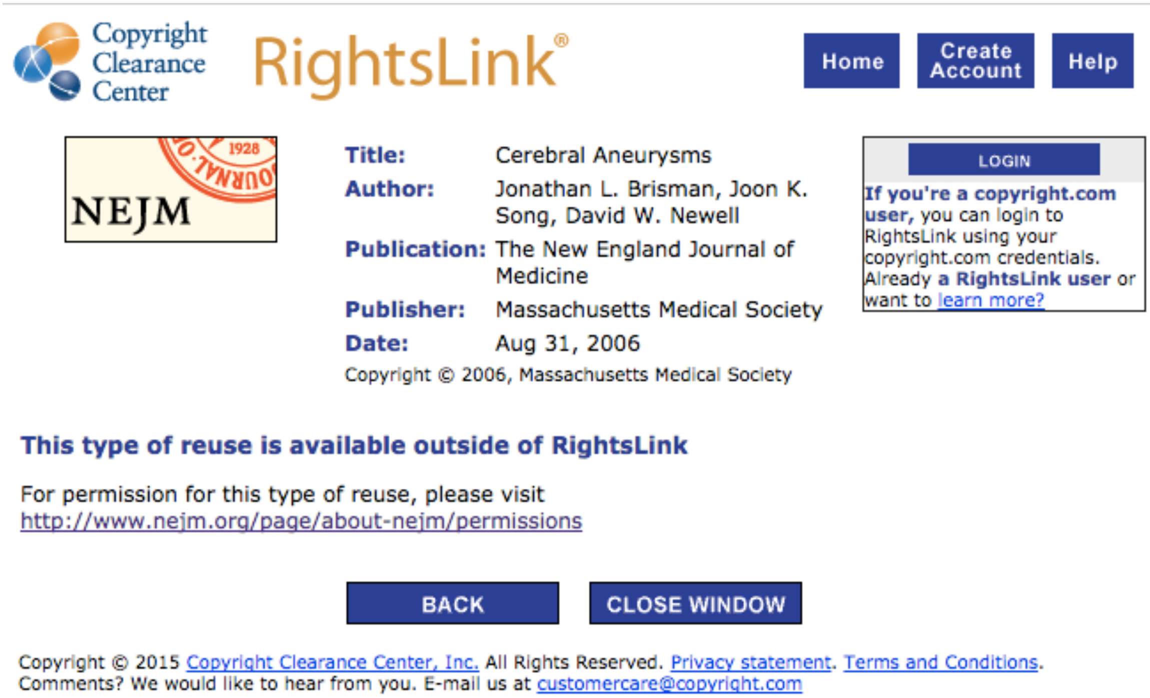

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## Appendix B: Statistical analysis from total procedure time between alternating and consistent groups

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| group | Sphericity Assumed | 42504.200 | 1 | 42504.200 | .150 | .718 | .036 | .150 | .061 |
| | Greenhouse-Geisser | 42504.200 | 1.000 | 42504.200 | .150 | .718 | .036 | .150 | .061 |
| | Huynh-Feldt | 42504.200 | 1.000 | 42504.200 | .150 | .718 | .036 | .150 | .061 |
| | Lower-bound | 42504.200 | 1.000 | 42504.200 | .150 | .718 | .036 | .150 | .061 |
| Error(group) | Sphericity Assumed | 1133123.68 | 4 | 283280.919 | | | | | |
| | Greenhouse-Geisser | 1133123.68 | 4.000 | 283280.919 | | | | | |
| | Huynh-Feldt | 1133123.68 | 4.000 | 283280.919 | | | | | |
| | Lower-bound | 1133123.68 | 4.000 | 283280.919 | | | | | |
| session_number | Sphericity Assumed | 5125124.80 | 7 | 732160.686 | 16.704 | .000 | .807 | 116.928 | 1.000 |
| | Greenhouse-Geisser | 5125124.80 | 2.146 | 2388028.61 | 16.704 | .001 | .807 | 35.850 | .994 |
| | Huynh-Feldt | 5125124.80 | 4.710 | 1088218.03 | 16.704 | .000 | .807 | 78.670 | 1.000 |
| | Lower-bound | 5125124.80 | 1.000 | 5125124.80 | 16.704 | .015 | .807 | 16.704 | .857 |
| Error(session_number) | Sphericity Assumed | 1227283.33 | 28 | 43831.547 | | | | | |
| | Greenhouse-Geisser | 1227283.33 | 8.585 | 142961.772 | | | | | |
| | Huynh-Feldt | 1227283.33 | 18.839 | 65147.284 | | | | | |
| | Lower-bound | 1227283.33 | 4.000 | 306820.831 | | | | | |

**Multivariate Tests**

| | Value | F | Hypothesis df | Error df | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[b] |
|---|---|---|---|---|---|---|---|---|
| Pillai's trace | .036 | .150[a] | 1.000 | 4.000 | .718 | .036 | .150 | .061 |
| Wilks' lambda | .964 | .150[a] | 1.000 | 4.000 | .718 | .036 | .150 | .061 |
| Hotelling's trace | .038 | .150[a] | 1.000 | 4.000 | .718 | .036 | .150 | .061 |
| Roy's largest root | .038 | .150[a] | 1.000 | 4.000 | .718 | .036 | .150 | .061 |

Each F tests the multivariate effect of group. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

**Mauchly's Test of Sphericity[a]**

Measure: MEASURE_1

| Within Subjects Effect | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon[b] Greenhouse-Geisser | Epsilon[b] Huynh-Feldt | Epsilon[b] Lower-bound |
|---|---|---|---|---|---|---|---|
| group | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| session_number | .000 | . | 27 | . | .307 | .673 | .143 |
| group * session_number | .000 | . | 27 | . | .388 | 1.000 | .143 |

**Pairwise Comparisons**

Measure: MEASURE_1

| (I) session_number | (J) session_number | Mean Difference (I-J) | Std. Error | Sig.[b] | 95% Confidence Interval for Difference[b] | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | 467.600 | 71.000 | .077 | -57.258 | 992.458 |
| | 3 | 554.400 | 132.297 | .386 | -423.590 | 1532.390 |
| | 4 | 584.200 | 179.630 | .877 | -743.690 | 1912.090 |
| | 5 | 768.800* | 87.948 | .026 | 118.660 | 1418.940 |
| | 6 | 740.900* | 76.602 | .018 | 174.629 | 1307.171 |
| | 7 | 795.500* | 92.539 | .028 | 111.419 | 1479.581 |
| | 8 | 816.200 | 114.335 | .057 | -29.008 | 1661.408 |
| 2 | 1 | -467.600 | 71.000 | .077 | -992.458 | 57.258 |
| | 3 | 86.800 | 79.915 | 1.000 | -503.958 | 677.558 |
| | 4 | 116.600 | 158.514 | 1.000 | -1055.192 | 1288.392 |
| | 5 | 301.200* | 32.486 | .021 | 61.049 | 541.351 |
| | 6 | 273.300 | 43.961 | .095 | -51.675 | 598.275 |
| | 7 | 327.900* | 33.546 | .017 | 79.916 | 575.884 |
| | 8 | 348.600 | 64.884 | .162 | -131.043 | 828.243 |
| 3 | 1 | -554.400 | 132.297 | .386 | -1532.390 | 423.590 |
| | 2 | -86.800 | 79.915 | 1.000 | -677.558 | 503.958 |
| | 4 | 29.800 | 145.883 | 1.000 | -1048.618 | 1108.218 |
| | 5 | 214.400 | 64.951 | .837 | -265.738 | 694.538 |
| | 6 | 186.500 | 67.117 | 1.000 | -309.649 | 682.649 |
| | 7 | 241.100 | 62.543 | .510 | -221.242 | 703.442 |
| | 8 | 261.800 | 75.073 | .705 | -293.167 | 816.767 |
| 4 | 1 | -584.200 | 179.630 | .877 | -1912.090 | 743.690 |
| | 2 | -116.600 | 158.514 | 1.000 | -1288.392 | 1055.192 |
| | 3 | -29.800 | 145.883 | 1.000 | -1108.218 | 1048.618 |
| | 5 | 184.600 | 128.118 | 1.000 | -762.493 | 1131.693 |
| | 6 | 156.700 | 125.646 | 1.000 | -772.117 | 1085.517 |
| | 7 | 211.300 | 141.948 | 1.000 | -838.031 | 1260.631 |
| | 8 | 232.000 | 125.696 | 1.000 | -697.186 | 1161.186 |
| 5 | 1 | -768.800* | 87.948 | .026 | -1418.940 | -118.660 |
| | 2 | -301.200* | 32.486 | .021 | -541.351 | -61.049 |
| | 3 | -214.400 | 64.951 | .837 | -694.538 | 265.738 |
| | 4 | -184.600 | 128.118 | 1.000 | -1131.693 | 762.493 |
| | 6 | -27.900 | 27.108 | 1.000 | -228.294 | 172.494 |
| | 7 | 26.700 | 22.581 | 1.000 | -140.229 | 193.629 |
| | 8 | 47.400 | 43.847 | 1.000 | -276.735 | 371.535 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | 1 | -740.900* | 76.602 | .018 | -1307.171 | -174.629 |
| | 2 | -273.300 | 43.961 | .095 | -598.275 | 51.675 |
| | 3 | -186.500 | 67.117 | 1.000 | -682.649 | 309.649 |
| | 4 | -156.700 | 125.646 | 1.000 | -1085.517 | 772.117 |
| | 5 | 27.900 | 27.108 | 1.000 | -172.494 | 228.294 |
| | 7 | 54.600 | 33.687 | 1.000 | -194.423 | 303.623 |
| | 8 | 75.300 | 49.264 | 1.000 | -288.875 | 439.475 |
| 7 | 1 | -795.500* | 92.539 | .028 | -1479.581 | -111.419 |
| | 2 | -327.900* | 33.546 | .017 | -575.884 | -79.916 |
| | 3 | -241.100 | 62.543 | .510 | -703.442 | 221.242 |
| | 4 | -211.300 | 141.948 | 1.000 | -1260.631 | 838.031 |
| | 5 | -26.700 | 22.581 | 1.000 | -193.629 | 140.229 |
| | 6 | -54.600 | 33.687 | 1.000 | -303.623 | 194.423 |
| | 8 | 20.700 | 33.760 | 1.000 | -228.863 | 270.263 |
| 8 | 1 | -816.200 | 114.335 | .057 | -1661.408 | 29.008 |
| | 2 | -348.600 | 64.884 | .162 | -828.243 | 131.043 |
| | 3 | -261.800 | 75.073 | .705 | -816.767 | 293.167 |
| | 4 | -232.000 | 125.696 | 1.000 | -1161.186 | 697.186 |
| | 5 | -47.400 | 43.847 | 1.000 | -371.535 | 276.735 |
| | 6 | -75.300 | 49.264 | 1.000 | -439.475 | 288.875 |
| | 7 | -20.700 | 33.760 | 1.000 | -270.263 | 228.863 |

**Tests of Normality**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| a1 | .243 | 5 | .200* | .827 | 5 | .131 |
| a2 | .155 | 5 | .200* | .995 | 5 | .994 |
| a3 | .349 | 5 | .047 | .776 | 5 | .051 |
| a4 | .308 | 5 | .136 | .866 | 5 | .252 |
| a5 | .275 | 5 | .200* | .875 | 5 | .288 |
| a6 | .262 | 5 | .200* | .838 | 5 | .160 |
| a7 | .275 | 5 | .200* | .932 | 5 | .613 |
| a8 | .209 | 5 | .200* | .942 | 5 | .681 |
| s1 | .289 | 5 | .200* | .854 | 5 | .209 |
| s2 | .251 | 5 | .200* | .846 | 5 | .181 |
| s3 | .268 | 5 | .200* | .866 | 5 | .250 |
| s4 | .388 | 5 | .013 | .677 | 5 | .005 |
| s5 | .232 | 5 | .200* | .953 | 5 | .762 |
| s6 | .280 | 5 | .200* | .891 | 5 | .362 |
| s7 | .194 | 5 | .200* | .972 | 5 | .889 |
| s8 | .297 | 5 | .172 | .818 | 5 | .113 |

## Appendix C: Statistical analysis from total procedure time between low and high MRT participants

**Multivariate Tests**[a]

| Effect | | Value | F | Hypothesis df | Error df | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[d] |
|---|---|---|---|---|---|---|---|---|---|
| MRT | Pillai's Trace | .938 | 45.013[b] | 1.000 | 3.000 | .007 | .938 | 45.013 | .987 |
| | Wilks' Lambda | .062 | 45.013[b] | 1.000 | 3.000 | .007 | .938 | 45.013 | .987 |
| | Hotelling's Trace | 15.004 | 45.013[b] | 1.000 | 3.000 | .007 | .938 | 45.013 | .987 |
| | Roy's Largest Root | 15.004 | 45.013[b] | 1.000 | 3.000 | .007 | .938 | 45.013 | .987 |

**Mauchly's Test of Sphericity**[a]

Measure: MEASURE_1

| Within Subjects Effect | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon[b] | | |
|---|---|---|---|---|---|---|---|
| | | | | | Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
| MRT | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| session | .000 | . | 27 | . | .385 | 1.000 | .143 |
| MRT * session | .000 | . | 27 | . | .286 | .861 | .143 |

**Tests of Within-Subjects Effects**

Measure: MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| MRT | Sphericity Assumed | 888070.641 | 1 | 888070.641 | 45.013 | .007 | .938 | 45.013 | .987 |
| | Greenhouse-Geisser | 888070.641 | 1.000 | 888070.641 | 45.013 | .007 | .938 | 45.013 | .987 |
| | Huynh-Feldt | 888070.641 | 1.000 | 888070.641 | 45.013 | .007 | .938 | 45.013 | .987 |
| | Lower-bound | 888070.641 | 1.000 | 888070.641 | 45.013 | .007 | .938 | 45.013 | .987 |
| Error(MRT) | Sphericity Assumed | 59188.172 | 3 | 19729.391 | | | | | |
| | Greenhouse-Geisser | 59188.172 | 3.000 | 19729.391 | | | | | |
| | Huynh-Feldt | 59188.172 | 3.000 | 19729.391 | | | | | |
| | Lower-bound | 59188.172 | 3.000 | 19729.391 | | | | | |
| session | Sphericity Assumed | 4974290.23 | 7 | 710612.891 | 14.792 | .000 | .831 | 103.546 | 1.000 |
| | Greenhouse-Geisser | 4974290.23 | 2.693 | 1846866.63 | 14.792 | .001 | .831 | 39.841 | .993 |
| | Huynh-Feldt | 4974290.23 | 7.000 | 710612.891 | 14.792 | .000 | .831 | 103.546 | 1.000 |
| | Lower-bound | 4974290.23 | 1.000 | 4974290.23 | 14.792 | .031 | .831 | 14.792 | .725 |
| Error(session) | Sphericity Assumed | 1008824.45 | 21 | 48039.260 | | | | | |
| | Greenhouse-Geisser | 1008824.45 | 8.080 | 124852.936 | | | | | |
| | Huynh-Feldt | 1008824.45 | 21.000 | 48039.260 | | | | | |
| | Lower-bound | 1008824.45 | 3.000 | 336274.818 | | | | | |

**Tests of Normality**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| a1 | .229 | 4 | . | .948 | 4 | .704 |
| a2 | .172 | 4 | . | .995 | 4 | .981 |
| a3 | .357 | 4 | . | .814 | 4 | .130 |
| a4 | .279 | 4 | . | .882 | 4 | .346 |
| a5 | .168 | 4 | . | .984 | 4 | .923 |
| a6 | .174 | 4 | . | .996 | 4 | .984 |
| a7 | .259 | 4 | . | .912 | 4 | .492 |
| a8 | .386 | 4 | . | .746 | 4 | .035 |
| s1 | .288 | 4 | . | .823 | 4 | .149 |
| s2 | .281 | 4 | . | .829 | 4 | .164 |
| s3 | .433 | 4 | . | .642 | 4 | .002 |
| s4 | .288 | 4 | . | .832 | 4 | .172 |
| s5 | .331 | 4 | . | .868 | 4 | .288 |
| s6 | .268 | 4 | . | .937 | 4 | .639 |
| s7 | .263 | 4 | . | .889 | 4 | .379 |
| s8 | .163 | 4 | . | .997 | 4 | .988 |

# Appendix D: Statistical analysis of total fluoroscopy time between alternating and consistent training groups

**Mauchly's Test of Sphericity[a]**

Measure: MEASURE_1

| Within Subjects Effect | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon[b] Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
|---|---|---|---|---|---|---|---|
| group | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| session_number | .000 | . | 27 | . | .339 | .866 | .143 |
| group * session_number | .000 | . | 27 | . | .391 | 1.000 | .143 |

**Tests of Within-Subjects Effects**

Measure: MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| group | Sphericity Assumed | 90.312 | 1 | 90.312 | .000 | .984 | .000 | .000 | .050 |
| | Greenhouse-Geisser | 90.312 | 1.000 | 90.312 | .000 | .984 | .000 | .000 | .050 |
| | Huynh-Feldt | 90.312 | 1.000 | 90.312 | .000 | .984 | .000 | .000 | .050 |
| | Lower-bound | 90.312 | 1.000 | 90.312 | .000 | .984 | .000 | .000 | .050 |
| Error(group) | Sphericity Assumed | 802149.000 | 4 | 200537.250 | | | | | |
| | Greenhouse-Geisser | 802149.000 | 4.000 | 200537.250 | | | | | |
| | Huynh-Feldt | 802149.000 | 4.000 | 200537.250 | | | | | |
| | Lower-bound | 802149.000 | 4.000 | 200537.250 | | | | | |
| session_number | Sphericity Assumed | 3604292.19 | 7 | 514898.884 | 13.885 | .000 | .776 | 97.198 | 1.000 |
| | Greenhouse-Geisser | 3604292.19 | 2.373 | 1518896.54 | 13.885 | .001 | .776 | 32.950 | .990 |
| | Huynh-Feldt | 3604292.19 | 6.063 | 594464.967 | 13.885 | .000 | .776 | 84.189 | 1.000 |
| | Lower-bound | 3604292.19 | 1.000 | 3604292.19 | 13.885 | .020 | .776 | 13.885 | .793 |
| Error(session_number) | Sphericity Assumed | 1038290.50 | 28 | 37081.804 | | | | | |
| | Greenhouse-Geisser | 1038290.50 | 9.492 | 109387.348 | | | | | |
| | Huynh-Feldt | 1038290.50 | 24.252 | 42811.965 | | | | | |
| | Lower-bound | 1038290.50 | 4.000 | 259572.625 | | | | | |

**Pairwise Comparisons**

Measure: MEASURE_1

| (I) session_number | (J) session_number | Mean Difference (I-J) | Std. Error | Sig.[b] | 95% Confidence Interval for Difference[b] | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | 394.800 | 55.537 | .058 | -15.748 | 805.348 |
| | 3 | 466.700 | 123.717 | .548 | -447.859 | 1381.259 |
| | 4 | 469.700 | 152.705 | 1.000 | -659.147 | 1598.547 |
| | 5 | 624.500 | 85.658 | .053 | -8.715 | 1257.715 |
| | 6 | 590.800* | 62.945 | .020 | 125.492 | 1056.108 |
| | 7 | 674.100* | 78.954 | .029 | 90.447 | 1257.753 |
| | 8 | 709.500* | 93.524 | .045 | 18.139 | 1400.861 |
| 2 | 1 | -394.800 | 55.537 | .058 | -805.348 | 15.748 |
| | 3 | 71.900 | 87.294 | 1.000 | -573.408 | 717.208 |
| | 4 | 74.900 | 146.405 | 1.000 | -1007.378 | 1157.178 |
| | 5 | 229.700 | 47.186 | .230 | -119.115 | 578.515 |
| | 6 | 196.000 | 51.376 | .528 | -183.792 | 575.792 |
| | 7 | 279.300 | 38.631 | .054 | -6.273 | 564.873 |
| | 8 | 314.700 | 65.404 | .240 | -168.789 | 798.189 |
| 3 | 1 | -466.700 | 123.717 | .548 | -1381.259 | 447.859 |
| | 2 | -71.900 | 87.294 | 1.000 | -717.208 | 573.408 |
| | 4 | 3.000 | 141.694 | 1.000 | -1044.454 | 1050.454 |
| | 5 | 157.800 | 65.956 | 1.000 | -329.771 | 645.371 |
| | 6 | 124.100 | 79.474 | 1.000 | -463.403 | 711.603 |
| | 7 | 207.400 | 76.267 | 1.000 | -356.394 | 771.194 |
| | 8 | 242.800 | 84.950 | 1.000 | -385.182 | 870.782 |
| 4 | 1 | -469.700 | 152.705 | 1.000 | -1598.547 | 659.147 |
| | 2 | -74.900 | 146.405 | 1.000 | -1157.178 | 1007.378 |
| | 3 | -3.000 | 141.694 | 1.000 | -1050.454 | 1044.454 |
| | 5 | 154.800 | 109.366 | 1.000 | -653.673 | 963.273 |
| | 6 | 121.100 | 102.074 | 1.000 | -633.468 | 875.668 |
| | 7 | 204.400 | 119.882 | 1.000 | -681.812 | 1090.612 |
| | 8 | 239.800 | 110.017 | 1.000 | -573.486 | 1053.086 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | 1 | -624.500 | 85.658 | .053 | -1257.715 | 8.715 |
| | 2 | -229.700 | 47.186 | .230 | -578.515 | 119.115 |
| | 3 | -157.800 | 65.956 | 1.000 | -645.371 | 329.771 |
| | 4 | -154.800 | 109.366 | 1.000 | -963.273 | 653.673 |
| | 6 | -33.700 | 35.184 | 1.000 | -293.795 | 226.395 |
| | 7 | 49.600 | 16.597 | 1.000 | -73.091 | 172.291 |
| | 8 | 85.000 | 34.318 | 1.000 | -168.691 | 338.691 |
| 6 | 1 | -590.800* | 62.945 | .020 | -1056.108 | -125.492 |
| | 2 | -196.000 | 51.376 | .528 | -575.792 | 183.792 |
| | 3 | -124.100 | 79.474 | 1.000 | -711.603 | 463.403 |
| | 4 | -121.100 | 102.074 | 1.000 | -875.668 | 633.468 |
| | 5 | 33.700 | 35.184 | 1.000 | -226.395 | 293.795 |
| | 7 | 83.300 | 39.260 | 1.000 | -206.925 | 373.525 |
| | 8 | 118.700 | 46.972 | 1.000 | -228.531 | 465.931 |
| 7 | 1 | -674.100* | 78.954 | .029 | -1257.753 | -90.447 |
| | 2 | -279.300 | 38.631 | .054 | -564.873 | 6.273 |
| | 3 | -207.400 | 76.267 | 1.000 | -771.194 | 356.394 |
| | 4 | -204.400 | 119.882 | 1.000 | -1090.612 | 681.812 |
| | 5 | -49.600 | 16.597 | 1.000 | -172.291 | 73.091 |
| | 6 | -83.300 | 39.260 | 1.000 | -373.525 | 206.925 |
| | 8 | 35.400 | 30.125 | 1.000 | -187.294 | 258.094 |
| 8 | 1 | -709.500* | 93.524 | .045 | -1400.861 | -18.139 |
| | 2 | -314.700 | 65.404 | .240 | -798.189 | 168.789 |
| | 3 | -242.800 | 84.950 | 1.000 | -870.782 | 385.182 |
| | 4 | -239.800 | 110.017 | 1.000 | -1053.086 | 573.486 |
| | 5 | -85.000 | 34.318 | 1.000 | -338.691 | 168.691 |
| | 6 | -118.700 | 46.972 | 1.000 | -465.931 | 228.531 |
| | 7 | -35.400 | 30.125 | 1.000 | -258.094 | 187.294 |

**Tests of Normality**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| a1 | .238 | 5 | .200* | .887 | 5 | .341 |
| a2 | .224 | 5 | .200* | .963 | 5 | .829 |
| a3 | .288 | 5 | .200* | .807 | 5 | .093 |
| a4 | .320 | 5 | .103 | .833 | 5 | .147 |
| a5 | .324 | 5 | .094 | .866 | 5 | .251 |
| a6 | .175 | 5 | .200* | .946 | 5 | .712 |
| a7 | .277 | 5 | .200* | .820 | 5 | .117 |
| a8 | .326 | 5 | .088 | .729 | 5 | .019 |
| s1 | .252 | 5 | .200* | .907 | 5 | .447 |
| s2 | .239 | 5 | .200* | .878 | 5 | .299 |
| s3 | .351 | 5 | .044 | .738 | 5 | .023 |
| s4 | .350 | 5 | .044 | .708 | 5 | .012 |
| s5 | .225 | 5 | .200* | .948 | 5 | .724 |
| s6 | .314 | 5 | .119 | .859 | 5 | .225 |
| s7 | .256 | 5 | .200* | .950 | 5 | .739 |
| s8 | .255 | 5 | .200* | .905 | 5 | .440 |

**Appendix E: Statistical analysis of correlation between total procedure time and total fluoroscopy time**

**Correlations**

| | | a1 | a2 |
|---|---|---|---|
| a1 | Pearson Correlation | 1 | .928** |
| | Sig. (1-tailed) | | .000 |
| | N | 115 | 115 |
| a2 | Pearson Correlation | .928** | 1 |
| | Sig. (1-tailed) | .000 | |
| | N | 115 | 115 |

**. Correlation is significant at the 0.01 level (1-tailed).

**Appendix F: Statistical analysis of total contrast injected between alternating and consistent groups**

**Pairwise Comparisons**

Measure: MEASURE_1

| (I) session_number | (J) session_number | Mean Difference (I-J) | Std. Error | Sig.[a] | 95% Confidence Interval for Difference[a] | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | 18.000 | 3.386 | .088 | -2.469 | 38.469 |
| | 3 | 20.000 | 8.764 | 1.000 | -32.974 | 72.974 |
| | 4 | 26.000 | 11.535 | 1.000 | -43.729 | 95.729 |
| | 5 | 32.667 | 11.380 | .979 | -36.124 | 101.458 |
| | 6 | 38.667 | 17.968 | 1.000 | -69.945 | 147.278 |
| | 7 | 30.667 | 13.009 | 1.000 | -47.972 | 109.305 |
| | 8 | 43.333 | 21.674 | 1.000 | -87.683 | 174.349 |
| 2 | 1 | -18.000 | 3.386 | .088 | -38.469 | 2.469 |
| | 3 | 2.000 | 8.050 | 1.000 | -46.659 | 50.659 |
| | 4 | 8.000 | 11.685 | 1.000 | -62.631 | 78.631 |
| | 5 | 14.667 | 13.091 | 1.000 | -64.466 | 93.799 |
| | 6 | 20.667 | 19.525 | 1.000 | -97.360 | 138.693 |
| | 7 | 12.667 | 14.548 | 1.000 | -75.272 | 100.606 |
| | 8 | 25.333 | 23.179 | 1.000 | -114.775 | 165.442 |
| 3 | 1 | -20.000 | 8.764 | 1.000 | -72.974 | 32.974 |
| | 2 | -2.000 | 8.050 | 1.000 | -50.659 | 46.659 |
| | 4 | 6.000 | 4.926 | 1.000 | -23.777 | 35.777 |
| | 5 | 12.667 | 10.604 | 1.000 | -51.432 | 76.765 |
| | 6 | 18.667 | 15.132 | 1.000 | -72.803 | 110.136 |
| | 7 | 10.667 | 9.942 | 1.000 | -49.431 | 70.764 |
| | 8 | 23.333 | 18.196 | 1.000 | -86.660 | 133.326 |
| 4 | 1 | -26.000 | 11.535 | 1.000 | -95.729 | 43.729 |
| | 2 | -8.000 | 11.685 | 1.000 | -78.631 | 62.631 |
| | 3 | -6.000 | 4.926 | 1.000 | -35.777 | 23.777 |
| | 5 | 6.667 | 8.176 | 1.000 | -42.754 | 56.088 |
| | 6 | 12.667 | 11.658 | 1.000 | -57.804 | 83.137 |
| | 7 | 4.667 | 7.036 | 1.000 | -37.867 | 47.200 |
| | 8 | 17.333 | 13.997 | 1.000 | -67.274 | 101.941 |
| 5 | 1 | -32.667 | 11.380 | .979 | -101.458 | 36.124 |
| | 2 | -14.667 | 13.091 | 1.000 | -93.799 | 64.466 |
| | 3 | -12.667 | 10.604 | 1.000 | -76.765 | 51.432 |
| | 4 | -6.667 | 8.176 | 1.000 | -56.088 | 42.754 |
| | 6 | 6.000 | 7.780 | 1.000 | -41.030 | 53.030 |
| | 7 | -2.000 | 5.910 | 1.000 | -37.727 | 33.727 |
| | 8 | 10.667 | 11.485 | 1.000 | -58.759 | 80.092 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | 1 | -38.667 | 17.968 | 1.000 | -147.278 | 69.945 |
| | 2 | -20.667 | 19.525 | 1.000 | -138.693 | 97.360 |
| | 3 | -18.667 | 15.132 | 1.000 | -110.136 | 72.803 |
| | 4 | -12.667 | 11.658 | 1.000 | -83.137 | 57.804 |
| | 5 | -6.000 | 7.780 | 1.000 | -53.030 | 41.030 |
| | 7 | -8.000 | 6.197 | 1.000 | -45.458 | 29.458 |
| | 8 | 4.667 | 4.890 | 1.000 | -24.892 | 34.225 |
| 7 | 1 | -30.667 | 13.009 | 1.000 | -109.305 | 47.972 |
| | 2 | -12.667 | 14.548 | 1.000 | -100.606 | 75.272 |
| | 3 | -10.667 | 9.942 | 1.000 | -70.764 | 49.431 |
| | 4 | -4.667 | 7.036 | 1.000 | -47.200 | 37.867 |
| | 5 | 2.000 | 5.910 | 1.000 | -33.727 | 37.727 |
| | 6 | 8.000 | 6.197 | 1.000 | -29.458 | 45.458 |
| | 8 | 12.667 | 9.204 | 1.000 | -42.968 | 68.302 |
| 8 | 1 | -43.333 | 21.674 | 1.000 | -174.349 | 87.683 |
| | 2 | -25.333 | 23.179 | 1.000 | -165.442 | 114.775 |
| | 3 | -23.333 | 18.196 | 1.000 | -133.326 | 86.660 |
| | 4 | -17.333 | 13.997 | 1.000 | -101.941 | 67.274 |
| | 5 | -10.667 | 11.485 | 1.000 | -80.092 | 58.759 |
| | 6 | -4.667 | 4.890 | 1.000 | -34.225 | 24.892 |
| | 7 | -12.667 | 9.204 | 1.000 | -68.302 | 42.968 |

**Tests of Within-Subjects Effects**

Measure: MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| group | Sphericity Assumed | 1666.667 | 1 | 1666.667 | .933 | .378 | .157 | .933 | .125 |
| | Greenhouse-Geisser | 1666.667 | 1.000 | 1666.667 | .933 | .378 | .157 | .933 | .125 |
| | Huynh-Feldt | 1666.667 | 1.000 | 1666.667 | .933 | .378 | .157 | .933 | .125 |
| | Lower-bound | 1666.667 | 1.000 | 1666.667 | .933 | .378 | .157 | .933 | .125 |
| Error(group) | Sphericity Assumed | 8933.333 | 5 | 1786.667 | | | | | |
| | Greenhouse-Geisser | 8933.333 | 5.000 | 1786.667 | | | | | |
| | Huynh-Feldt | 8933.333 | 5.000 | 1786.667 | | | | | |
| | Lower-bound | 8933.333 | 5.000 | 1786.667 | | | | | |
| session_number | Sphericity Assumed | 15634.667 | 7 | 2233.524 | 2.351 | .044 | .320 | 16.456 | .773 |
| | Greenhouse-Geisser | 15634.667 | 1.377 | 11356.685 | 2.351 | .170 | .320 | 3.236 | .290 |
| | Huynh-Feldt | 15634.667 | 1.728 | 9049.166 | 2.351 | .156 | .320 | 4.062 | .335 |
| | Lower-bound | 15634.667 | 1.000 | 15634.667 | 2.351 | .186 | .320 | 2.351 | .240 |
| Error(session_number) | Sphericity Assumed | 33253.333 | 35 | 950.095 | | | | | |
| | Greenhouse-Geisser | 33253.333 | 6.883 | 4830.901 | | | | | |
| | Huynh-Feldt | 33253.333 | 8.639 | 3849.330 | | | | | |
| | Lower-bound | 33253.333 | 5.000 | 6650.667 | | | | | |

**Tests of Normality**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| a1 | .234 | 5 | .200* | .928 | 5 | .585 |
| a2 | .237 | 5 | .200* | .961 | 5 | .814 |
| a3 | .261 | 5 | .200* | .859 | 5 | .223 |
| a4 | .241 | 5 | .200* | .821 | 5 | .119 |
| a5 | .473 | 5 | .001 | .552 | 5 | .000 |
| a6 | .304 | 5 | .149 | .817 | 5 | .111 |
| a7 | .367 | 5 | .026 | .684 | 5 | .006 |
| a8 | .473 | 5 | .001 | .552 | 5 | .000 |
| s1 | .335 | 5 | .069 | .860 | 5 | .228 |
| s2 | .273 | 5 | .200* | .852 | 5 | .201 |
| s3 | .473 | 5 | .001 | .552 | 5 | .000 |
| s4 | .450 | 5 | .001 | .638 | 5 | .002 |
| s5 | .221 | 5 | .200* | .902 | 5 | .421 |
| s6 | .367 | 5 | .026 | .684 | 5 | .006 |
| s7 | .258 | 5 | .200* | .782 | 5 | .057 |
| s8 | .201 | 5 | .200* | .881 | 5 | .314 |

**Mauchly's Test of Sphericity[a]**

Measure: MEASURE_1

| | | | | | Epsilon[b] | | |
|---|---|---|---|---|---|---|---|
| Within Subjects Effect | Mauchly's W | Approx. Chi-Square | df | Sig. | Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
| group | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| session_number | .000 | . | 27 | . | .197 | .247 | .143 |
| group * session_number | .000 | . | 27 | . | .196 | .246 | .143 |

## Appendix G: Statistical analysis of total procedure time, total fluoroscopy time, and contrast injected correlations

**Correlations**

| | | Total Procedure Time | Total Fluoroscopy Time | Contrast Injected |
|---|---|---|---|---|
| Total Procedure Time | Pearson Correlation | 1 | .928** | .481** |
| | Sig. (2-tailed) | | .000 | .000 |
| | N | 115 | 115 | 115 |
| Total Fluoroscopy Time | Pearson Correlation | .928** | 1 | .283** |
| | Sig. (2-tailed) | .000 | | .002 |
| | N | 115 | 115 | 115 |
| Contrast Injected | Pearson Correlation | .481** | .283** | 1 |
| | Sig. (2-tailed) | .000 | .002 | |
| | N | 115 | 115 | 115 |

## Appendix H: Statistical analysis of number of roadmaps created between alternating and consistent groups

**Mauchly's Test of Sphericity[a]**

Measure: MEASURE_1

| Within Subjects Effect | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilon[b] Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
|---|---|---|---|---|---|---|---|
| group | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| session_number | .000 | . | 27 | . | .375 | .829 | .143 |
| group * session_number | .000 | . | 27 | . | .326 | .614 | .143 |

**Tests of Within-Subjects Effects**

Measure: MEASURE_1

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|---|
| group | Sphericity Assumed | 1.042 | 1 | 1.042 | .121 | .742 | .024 | .121 | .059 |
| | Greenhouse-Geisser | 1.042 | 1.000 | 1.042 | .121 | .742 | .024 | .121 | .059 |
| | Huynh-Feldt | 1.042 | 1.000 | 1.042 | .121 | .742 | .024 | .121 | .059 |
| | Lower-bound | 1.042 | 1.000 | 1.042 | .121 | .742 | .024 | .121 | .059 |
| Error(group) | Sphericity Assumed | 43.083 | 5 | 8.617 | | | | | |
| | Greenhouse-Geisser | 43.083 | 5.000 | 8.617 | | | | | |
| | Huynh-Feldt | 43.083 | 5.000 | 8.617 | | | | | |
| | Lower-bound | 43.083 | 5.000 | 8.617 | | | | | |
| session_number | Sphericity Assumed | 111.792 | 7 | 15.970 | 2.673 | .025 | .348 | 18.714 | .833 |
| | Greenhouse-Geisser | 111.792 | 2.627 | 42.548 | 2.673 | .096 | .348 | 7.024 | .490 |
| | Huynh-Feldt | 111.792 | 5.801 | 19.270 | 2.673 | .036 | .348 | 15.509 | .769 |
| | Lower-bound | 111.792 | 1.000 | 111.792 | 2.673 | .163 | .348 | 2.673 | .266 |
| Error(session_number) | Sphericity Assumed | 209.083 | 35 | 5.974 | | | | | |
| | Greenhouse-Geisser | 209.083 | 13.137 | 15.916 | | | | | |
| | Huynh-Feldt | 209.083 | 29.007 | 7.208 | | | | | |
| | Lower-bound | 209.083 | 5.000 | 41.817 | | | | | |

**Tests of Normality**

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| a1 | .210 | 6 | .200* | .877 | 6 | .256 |
| a2 | .214 | 6 | .200* | .958 | 6 | .804 |
| a3 | .210 | 6 | .200* | .889 | 6 | .315 |
| a4 | .223 | 6 | .200* | .908 | 6 | .421 |
| a5 | .404 | 6 | .003 | .692 | 6 | .005 |
| a6 | .388 | 6 | .005 | .779 | 6 | .038 |
| a7 | .291 | 6 | .123 | .738 | 6 | .015 |
| a8 | .333 | 6 | .036 | .827 | 6 | .101 |
| s1 | .201 | 6 | .200* | .912 | 6 | .452 |
| s2 | .292 | 6 | .120 | .796 | 6 | .054 |
| s3 | .403 | 6 | .003 | .697 | 6 | .006 |
| s4 | .338 | 6 | .031 | .672 | 6 | .003 |
| s5 | .183 | 6 | .200* | .960 | 6 | .820 |
| s6 | .333 | 6 | .036 | .721 | 6 | .010 |
| s7 | .208 | 6 | .200* | .908 | 6 | .425 |
| s8 | .315 | 6 | .064 | .881 | 6 | .275 |

| (I) session_number | (J) session_number | Mean Difference (I-J) | Std. Error | Sig.[a] | 95% Confidence Interval for Difference[a] | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 1 | 2 | 1.500 | .742 | 1.000 | -2.983 | 5.983 |
| | 3 | 1.833 | 1.515 | 1.000 | -7.323 | 10.990 |
| | 4 | 2.500 | 1.544 | 1.000 | -6.832 | 11.832 |
| | 5 | 3.250 | .750 | .209 | -1.284 | 7.784 |
| | 6 | 2.917 | 1.060 | 1.000 | -3.491 | 9.324 |
| | 7 | 2.167 | 1.085 | 1.000 | -4.393 | 8.727 |
| | 8 | 3.667 | 1.295 | 1.000 | -4.163 | 11.496 |
| 2 | 1 | -1.500 | .742 | 1.000 | -5.983 | 2.983 |
| | 3 | .333 | .872 | 1.000 | -4.940 | 5.607 |
| | 4 | 1.000 | 1.008 | 1.000 | -5.095 | 7.095 |
| | 5 | 1.750 | .834 | 1.000 | -3.292 | 6.792 |
| | 6 | 1.417 | .935 | 1.000 | -4.233 | 7.067 |
| | 7 | .667 | .703 | 1.000 | -3.584 | 4.917 |
| | 8 | 2.167 | 1.101 | 1.000 | -4.486 | 8.819 |
| 3 | 1 | -1.833 | 1.515 | 1.000 | -10.990 | 7.323 |
| | 2 | -.333 | .872 | 1.000 | -5.607 | 4.940 |
| | 4 | .667 | .782 | 1.000 | -4.059 | 5.392 |
| | 5 | 1.417 | 1.200 | 1.000 | -5.838 | 8.671 |
| | 6 | 1.083 | 1.091 | 1.000 | -5.511 | 7.678 |
| | 7 | .333 | .615 | 1.000 | -3.382 | 4.049 |
| | 8 | 1.833 | 1.333 | 1.000 | -6.226 | 9.893 |
| 4 | 1 | -2.500 | 1.544 | 1.000 | -11.832 | 6.832 |
| | 2 | -1.000 | 1.008 | 1.000 | -7.095 | 5.095 |
| | 3 | -.667 | .782 | 1.000 | -5.392 | 4.059 |
| | 5 | .750 | 1.116 | 1.000 | -5.997 | 7.497 |
| | 6 | .417 | .841 | 1.000 | -4.666 | 5.499 |
| | 7 | -.333 | .972 | 1.000 | -6.208 | 5.541 |
| | 8 | 1.167 | .760 | 1.000 | -3.428 | 5.761 |
| 5 | 1 | -3.250 | .750 | .209 | -7.784 | 1.284 |
| | 2 | -1.750 | .834 | 1.000 | -6.792 | 3.292 |
| | 3 | -1.417 | 1.200 | 1.000 | -8.671 | 5.838 |
| | 4 | -.750 | 1.116 | 1.000 | -7.497 | 5.997 |
| | 6 | -.333 | .477 | 1.000 | -3.218 | 2.552 |
| | 7 | -1.083 | .688 | 1.000 | -5.243 | 3.077 |
| | 8 | .417 | .970 | 1.000 | -5.445 | 6.278 |

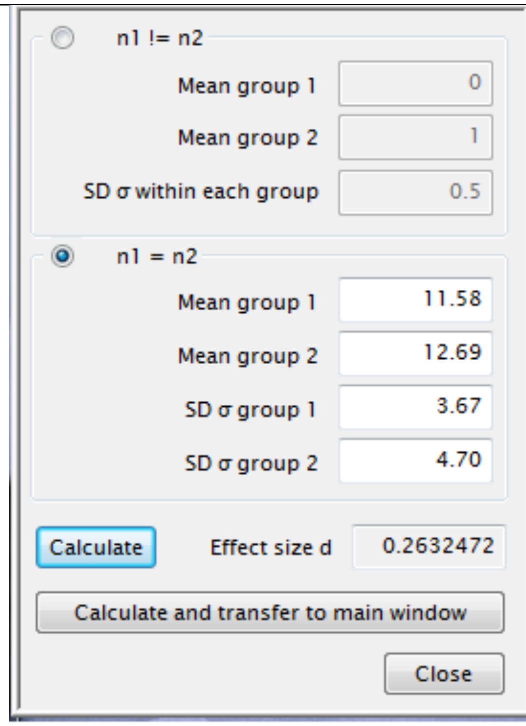
| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | 1 | -2.917 | 1.060 | 1.000 | -9.324 | 3.491 |
| | 2 | -1.417 | .935 | 1.000 | -7.067 | 4.233 |
| | 3 | -1.083 | 1.091 | 1.000 | -7.678 | 5.511 |
| | 4 | -.417 | .841 | 1.000 | -5.499 | 4.666 |
| | 5 | .333 | .477 | 1.000 | -2.552 | 3.218 |
| | 7 | -.750 | .772 | 1.000 | -5.416 | 3.916 |
| | 8 | .750 | .629 | 1.000 | -3.053 | 4.553 |
| 7 | 1 | -2.167 | 1.085 | 1.000 | -8.727 | 4.393 |
| | 2 | -.667 | .703 | 1.000 | -4.917 | 3.584 |
| | 3 | -.333 | .615 | 1.000 | -4.049 | 3.382 |
| | 4 | .333 | .972 | 1.000 | -5.541 | 6.208 |
| | 5 | 1.083 | .688 | 1.000 | -3.077 | 5.243 |
| | 6 | .750 | .772 | 1.000 | -3.916 | 5.416 |
| | 8 | 1.500 | 1.245 | 1.000 | -6.026 | 9.026 |
| 8 | 1 | -3.667 | 1.295 | 1.000 | -11.496 | 4.163 |
| | 2 | -2.167 | 1.101 | 1.000 | -8.819 | 4.486 |
| | 3 | -1.833 | 1.333 | 1.000 | -9.893 | 6.226 |
| | 4 | -1.167 | .760 | 1.000 | -5.761 | 3.428 |
| | 5 | -.417 | .970 | 1.000 | -6.278 | 5.445 |
| | 6 | -.750 | .629 | 1.000 | -4.553 | 3.053 |
| | 7 | -1.500 | 1.245 | 1.000 | -9.026 | 6.026 |

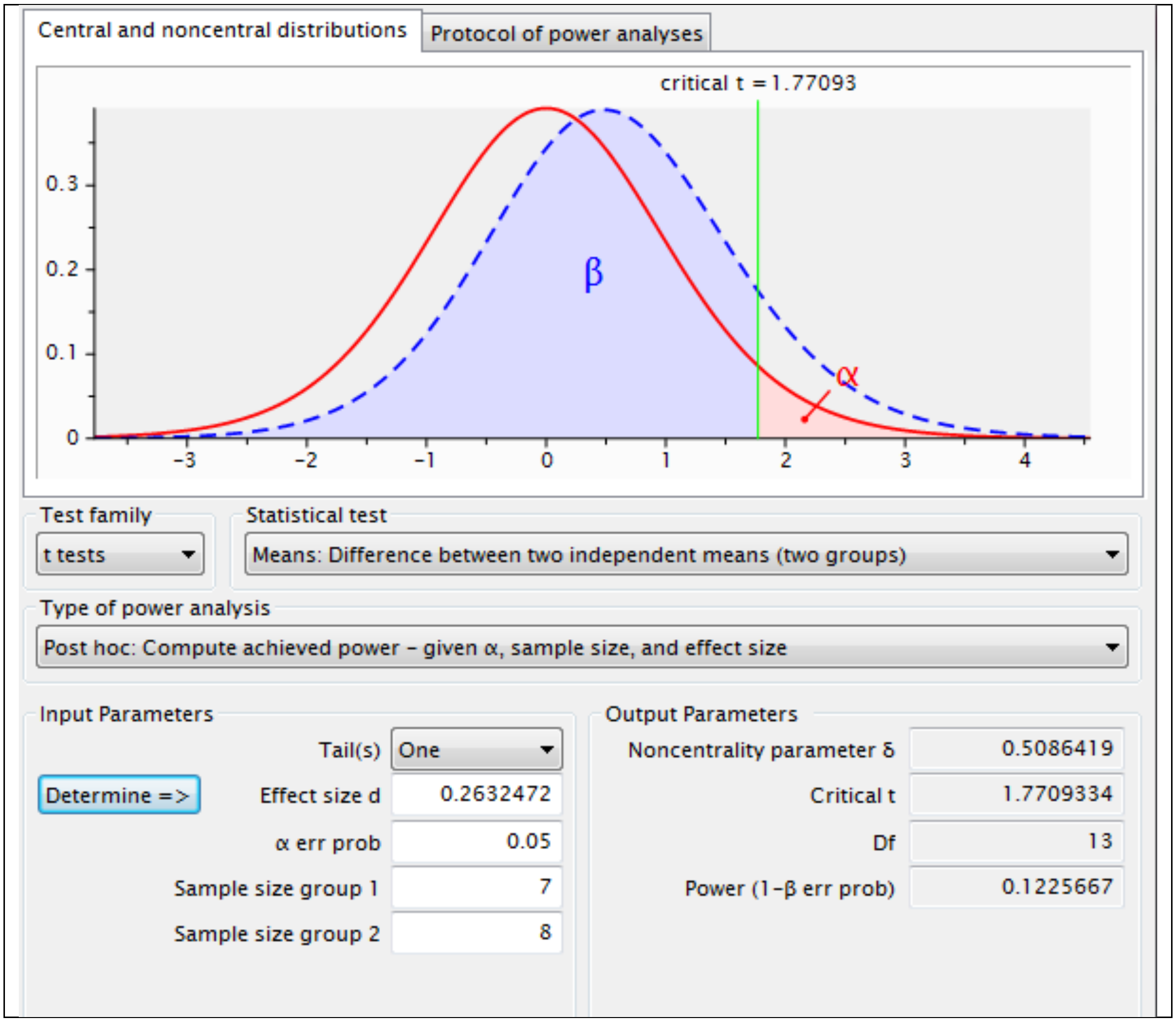
---

**Appendix I: Independent samples t-test assessing the MRT values between alternating and consistent groups**

**Independent Samples Test**

| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Confidence Interval of the Difference | |
| | | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | Lower | Upper |
| PERFORMANCE | Equal variances assumed | .411 | .533 | -.507 | 13 | .621 | -1.11607 | 2.20132 | -5.87173 | 3.63959 |
| | Equal variances not assumed | | | -.516 | 12.866 | .615 | -1.11607 | 2.16336 | -5.79469 | 3.56255 |


n1 != n2
Mean group 1
0
Mean group 2
1
SD σ within each group
0.5
n1 = n2
Mean group 1
11.58
Mean group 2
12.69
SD σ group 1
3.67
SD σ group 2
4.70
Calculate
Effect size d
0.2632472
Calculate and transfer to main window
Close


Central and noncentral distributions
Protocol of power analyses
critical t = 1.77093
β
α
0.3
0.2
0.1
0
-3
-2
-1
0
1
2
3
4
Test family
t tests
Statistical test
Means: Difference between two independent means (two groups)
Type of power analysis
Post hoc: Compute achieved power – given α, sample size, and effect size
Input Parameters
Tail(s)
One
Determine =>
Effect size d
0.2632472
α err prob
0.05
Sample size group 1
7
Sample size group 2
8
Output Parameters
Noncentrality parameter δ
0.5086419
Critical t
1.7709334
Df
13
Power (1-β err prob)
0.1225667

Curriculum Vitae

# Oleksiy Zaika

**51 Apeldoorn Cres.- London - ON - N5Y 2B5 - (226) 374-4399 - ozaika@uwo.ca**

## EDUCATION

**Masters of Science in Clinical Anatomy** **Sep 2013 – Apr 2015 (anticipated)**

Department of Anatomy & Cell Biology, Schulich School of Medicine and Dentistry, University of Western Ontario (Western), London, Ontario

- Research - *Evaluation of User Performance in Simulation-Based Diagnostic Cerebral Angiography Training*

**Bachelor of Science in Biomedical Sciences (Honours)** **Sep 2008 – Jun 2013**
Department of Life Sciences, University of Guelph, Guelph, Ontario
Specialization in Neuroscience

- Research in Neuroscience – *Importance of Histone Acetylation in Object-in-Place Memory in Rats*

## TEACHING & MENTORSHIP EXPERIENCE

**Teaching Assistant** **Jan 2015 – Present**
ACB 2221 - Functional Human Gross Anatomy for Kinesiology, Western

**Anatomy Outreach Facilitator** **Oct 2013 – Present**
Western

**Sessional Instructor** **Jan 2014 – Dec 2014**
PSYC/BIOL 2606 – Brain and Behaviour, Algoma University, St. Thomas campus

**Teaching Assistant** **Sep 2014 – Dec 2014**
Medicine Year 1 & 2, Human Anatomy, Schulich School of Medicine and Dentistry, Western

**Guest Lecturer** **Oct 2014**
ACB 3319 - Systemic Human Anatomy, Western

**Teaching Assistant** **Sep 2013 – Apr 2014**
ACB 3319 - Systemic Human Anatomy, Western

**Teaching Assistant** **Sep 2013 – Dec 2013**

HS 2300/KIN 2222 - Systemic Approach to Functional Anatomy, Western

**Program Facilitator/Instructor** **Sep 2012 – Apr 2013**
Human Anatomy Outreach Program, University of Guelph

**Club President** **May 2012 – Apr 2013**
University of Guelph Pre-Med Club, University of Guelph
**Residence Assistant** **Aug 2009 – Apr 2010**
University of Guelph Residence Life

## PROFESSIONAL DEVELOPMENT

**Certificate in University Teaching and Learning** **Apr 2015**

**Winter Conference on Teaching** **Jan 2015**

**Let's Talk Science Educator** **Sep 2013**

**LEAD@Guelph Leadership Foundations Certificate** **Jun 2013**

**Brain Day Presenter with Parachute© Canada** **Apr 2013**

**Invited Speaker for Last Lecture/Valedictorian Session** **Apr 2013**

## CONFERENCE POSTERS

Zaika, O., Nguyen, N., Boulton, M., Eagleson, R., de Ribaupierre, S. (2015). Effectiveness of Simulation-Based Training in Aneurysm Diagnosis & Coiling in Cerebral Angiography. Presented at the 2015 Experimental Biology conference, Boston, MA.

Zaika, O., Nguyen, N., Boulton, M., Eagleson, R., de Ribaupierre, S. (2014). Effectiveness of Simulated Aneurysm Diagnosis and Coiling in Cerebral Angiography. Presented at the 2014 Anatomy and Cell Biology Research Day conference, London, ON.

Zaika, O., Mitchnick, K.A., Winters, B.D. (2013). The role of histone acetylation in object-in-place memory in rats. Presented at the 2013 Neuroscience Day conference, Guelph, ON.

## CONFERENCE ORAL PRESENTATIONS

Zaika, O., Nguyen, N., Boulton, M., Eagleson, R., de Ribaupierre, S. (2015). Evaluating simulator performance in diagnostic cerebral angiography. Presented at the 2015 CNS Departmental Research Day conference, London, ON.

## MEMBERSHIPS

Member of the *American Association of Anatomists (AAA)*

## SCHOLARSHIPS AND AWARDS

| | |
|---|---|
| American Association of Anatomists Student Travel Scholarship | **Apr 2015** |
| Western Graduate Research Scholarship | **Sep 2013** |
| University of Guelph Entrance Scholarship | **Sep 2008** |