and After the 2017 Motors Skills Course of the Southwest Orthopaedic Trauma Association

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Funding This project was funded in part by the Scholarship in Education Allocations Committee (SEAC).

ABSTRACT

Background: Although experience within the operating room can help surgeons learn simple bone-drilling techniques, outside training may be better suited for complex procedures. We adapted a rotary handpiece to evaluate bone drilling skills of orthopaedic resident physicians during the 2017 motor skills course of the Southwest Orthopaedic Trauma Association (SWOTA).

Methods: A total of 25 postgraduate year-one orthopaedic residents from seven institutions were asked to perform a bicortical drilling task three times before and after attending a motor skills course. Kinetic and kinematic data were collected using force, acceleration, and visual sensors.

Results: A total of 16 parameters were measured. Variables statistically significant after the course were as follows: over-penetration (28.8-18.2 mm), skiving (22%-6%), preparation time (27.3-9.65 seconds), drilling time (8.28-9.35 seconds), palmar-dorsal vibration (1.76-2.05 m/s^2), maximum drilling force (58.56-84.30 N), and maximum revolution per minute (RPM; 917-944). The interdependence of these parameters taken separately for pre- and post-course performance are presented. Notable correlations include: over-penetration with force (0.65), palmar-dorsal toggle (0.65), vibration in palmar-dorsal (0.53), time (-0.41), and RPM (-0.36); time with both RPM (0.38) and palmar-dorsal toggle (-0.40); and force with both RPM (-0.41) and palmar-dorsal toggle (0.32).

Conclusions: The correlation data presented provide insight into patterns between measured parameters regarding where performance metrics are and are not coupled. Evidence for motor skill acquisition across both short- and long-time scales are elucidated.

Keywords: Resident Training, Surgical Skill, Skill Assessment

INTRODUCTION

The specialty of orthopaedic surgery demands a range of motor skills that require deliberate training. Historically, these skills were primarily acquired in the operating room (OR). Although this may be an effective method of training for treating simple fractures or low-risk injuries, more complicated operations or high-risk situations (eg, spinal procedures, potential for vascular or nerve injury, etc) should be simulated in the laboratory before performing the tasks in the OR. Orthopaedic surgery was one of the earliest surgical fields to teach surgical skills to residents outside of the OR.

In 1975, Lippert et al[1] offered a motor skills course at the University of Washington. Since then the modes for and interest in this type of training have continued to grow.[2,3] Meanwhile, an increasingly clear picture has been developed for patient safety[4] and costs associated with surgical complications.[5] It has been estimated that including residents in general surgery cases and subsequent time loss results in a national annual cost of $53 million.[6]

Simulated surgical procedures (or focused skills laboratory) have several clear advantages, including reduced stress to residents. Furthermore, a particular aspect can be trained, which can result in more rapid acquisition of particular skills.[2,7-13] As of July 2013, the Patient Protection and Affordable Care Act prompted the American Board of Orthopaedic Surgeons (ABOS) and the Residency Review Committee (RRC) for Orthopaedic Surgery to mandate formal motor skills training outside of the OR.[14,15] Many orthopaedic procedures involve drilling holes in bone. The drilling of a "good" hole entails precise location and orientation while avoiding the use of excessive force, over-penetration, toggle, and skiving.[16-21] The objective of this study was to quantify the surgical performance of residents before and after a motor skills course.

METHOD

Hardware

Fundamentally, the hardware design of the current study aimed to facilitate quantification of all parameters related to the failure or success of drilling a "good" hole in the context of orthopaedic surgery. The device used is an improvement upon similar devices used in previous years (Figure 1).[16,17,21] With each iteration, the goal has been to maximally preserve (or improve upon) the utility compared to previous devices while reducing device cost, size, and complexity. The hardware consists of 1) a modified Stryker 4203 System 5-rotary Handpiece (Stryker Industries, Kalamazoo, MI) with dual-trigger and drilling attachments; 2) a synthetic bone fixture with integrated force sensor and camera; and 3) various electronic and computer components to read from sensors, analyze data, and allow visualization of results. Additionally, a thermal imaging camera was used to observe specimen heating during drilling (FLIR T640, FLIR Systems Inc, Wilsonville, NC).

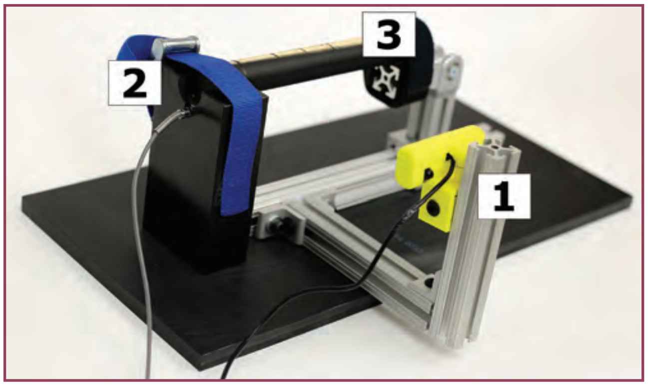


Figure 1. A custom fixture was built to hold the bone analog, support a small camera (1) used, in part, for measuring over-penetration, and a load cell (2) for measuring applied load. At one end of the fixture, the sample is supported by a hinge joint (3), and the button load cell (2) provides the support force at the other end. Actual force measurement required knowing where the drill was positioned along the length of the bone. This was controlled for during the experiment.

Parameters measured included drill orientation and vibration, over-penetration, applied force, drill revolution per minute (RPM), skiving, and drill-bit temperature. Drill orientation (ie, roll, pitch, and yaw), vibration, and rotational speed were measured using a combination of a Bosch BNO055 9-DOF orientation sensor (Robert Bosch GmbH, Stuttgart, Germany) and an external, calibrated camera. The accelerometer and other hardware were assembled into the battery housing to provide constant external power supply. External power was used to ensure that drill performance did not change with variations in battery performance or from participant to participant. The synthetic bone fixture included a camera-mount that eliminated the need for re-registration and incorporated a load cell to measure the force applied during drilling (Figure 1). Drill speed was measured using a small magnet attached to the chuck along with a reed switch and associated electronics attached to the drill body (Figure 2).

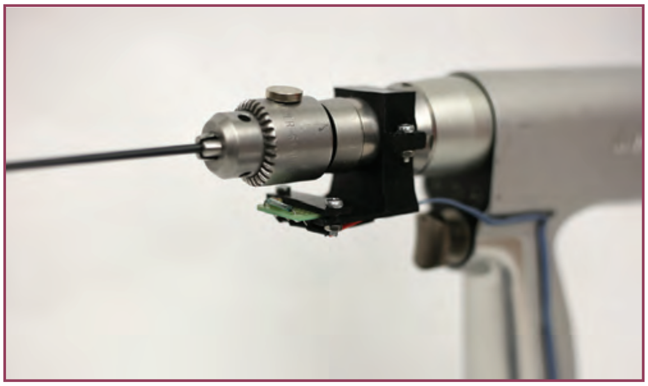


Figure 2. Drill speed was measured using a small magnet attached to the drill chuck. Adjacent to this, and supported by the drill body, a reed switch allowed measurement of chuck rotation. This signal was decoded by a computer algorithm.

Data from the kinematic sensors and camera were recorded using an Arduino Uno microcontroller and a desktop computer (Intel Core i7, 6700 3.4GHz processor, 8GB RAM). Force data were recorded using a CompactDAQ (National Instruments Corporation, Austin, TX) data acquisition system and a second desktop computer (dual core Intel, 2.4GHz processor, 32GB RAM). Sufficient performance required tuning and careful synchronization of these data streams. Among the technical solutions, a Python script was used to synchronously pull sensor data from the Arduino serial ports (one thread) while pulling frames (separate thread) from the camera at 52 frames per second. A manual control box was used to cue data recording on both machines. Figure 3 shows some representative parameters obtained.

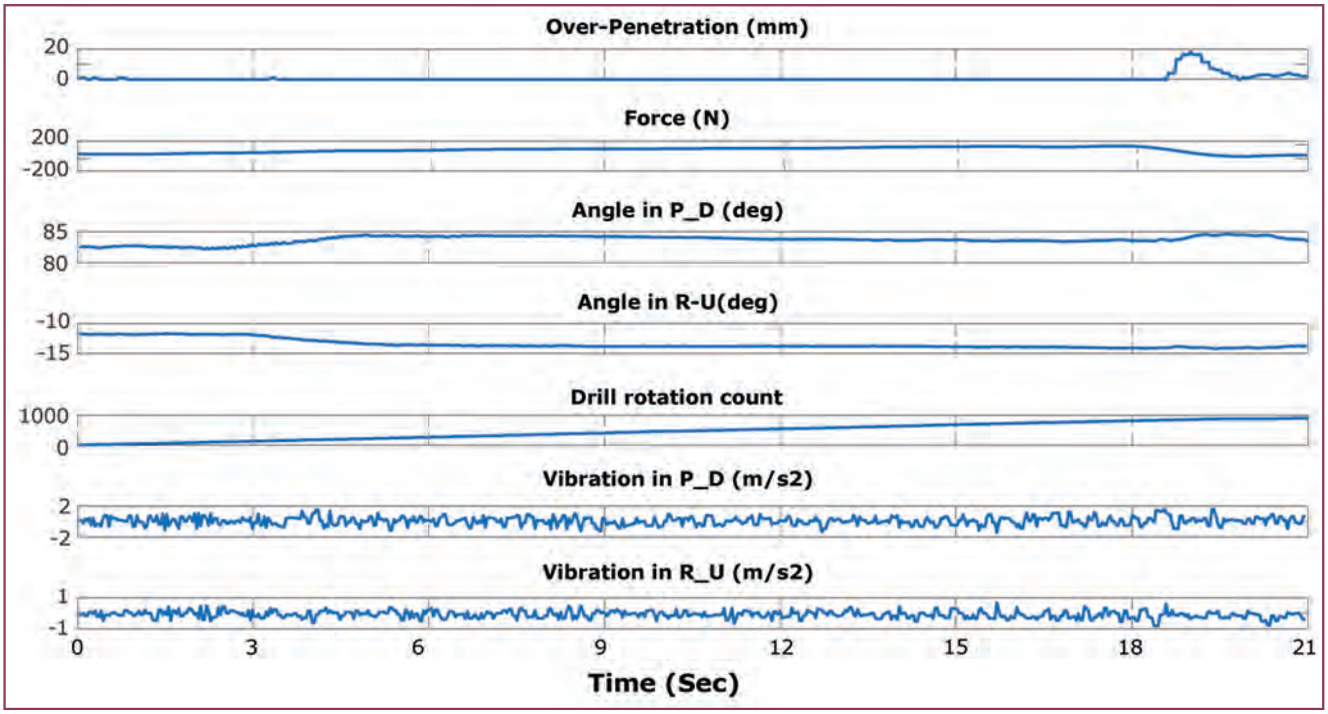


Figure 3. Representative data for some of the parameters measured. Over-penetration was measured using a camera (52 frames per second) along with accelerometer data (45 Hz). Here, over-penetration is calculated to be zero until at about 19 seconds, when it begins to spike to 20 mm. Force data were recorded using a load cell and CompactDAQ (National Instruments Corporation, Austin, TX) at 1.4 kHz. Here, the force is seen to steadily increase to 110.9 N, then drop shortly before the drill exits the sample. Similarly, five other parameters that describe drill orientation (both in the palmar-dorsal and radial-ulnar directions), drill revolution per minute (rotation count), and drill vibration are depicted (all captured at 45 Hz).

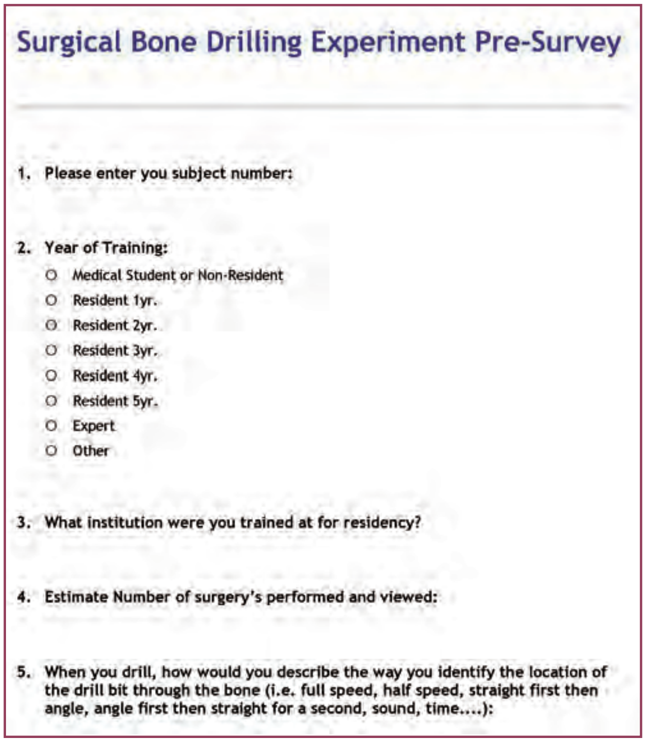
Participants

This study was approved by the Human Research Review Committee at The University of New Mexico Health Sciences Center (HRRC #15-087). Participants were recruited during the 2017 motor skills course held by SWOTA for postgraduate year-one orthopaedic residents in Albuquerque, NM. The event is an ABOS-approved surgical skills training course joined by 25 residents (9 women, 16 men) in orthopaedic residency programs from New Mexico, Arizona, Texas, and Nevada.

Task Design

Before the start of the course, participants completed a survey to quantify prior experience and other relevant factors (Figure 4). During the task, each participant was asked to drill a perpendicular hole through the entire cross-section of a 2.54-cm (1-in) aspen dowel, while taking into consideration any performance factors relevant to bicortical drilling in a clinical setting. This task was performed three times. A fourth hole was requested if a false start, measurement error, or similar factors affected data collection for any of the three performances.

After the task, participants were trained for 3 days in splinting and casting, external fixation, K-wire use, internal fixation basics, olecranon osteotomy, plating



Surgical Bone Drilling Experiment Pre-Survey

1. Please enter you subject number:

2. Year of Training:
   - ○ Medical Student or Non-Resident
   - ○ Resident 1yr.
   - ○ Resident 2yr.
   - ○ Resident 3yr.
   - ○ Resident 4yr.
   - ○ Resident 5yr.
   - ○ Expert
   - ○ Other

3. What institution were you trained at for residency?

4. Estimate Number of surgery's performed and viewed:

5. When you drill, how would you describe the way you identify the location of the drill bit through the bone (i.e. full speed, half speed, straight first then angle, angle first then straight for a second, sound, time....):

Figure 4. Survey provided to participants before the first test.

basics, distal femur locking plates, proximal tibia locking plates, incision, exposure, and soft-tissue handling (cadaver), compartment syndrome, distal radius repair, and fingertip repair. After 3 days of training, we asked each participant to repeat the task.

Data Capture and Analysis

Over-penetration was measured in real time by combining the orientation of the drill per the accelerometer with a Creative Live HD 720p camera (Creative Technology, Singapore, Australia) to view the underside of the drilling sample. During drilling, debris tends to fall in the area viewed by the camera for over-penetration. To ignore this noise source, eroding, dilating, and Gaussian filters were used to differentiate the drill bit from the debris. To maximize visual contrast, care was taken to color the drilling sample, background, and selection of drill bit. After each parameter was processed, the Matlab function corrplot was used to determine correlation coefficients (parameter interdependence). Pre- versus post-course performance differences were tested for statistical significance using Matlab's *anova1* function (single factor).

RESULTS

Information gathered from the survey, experimenter observations, and integrated data acquisition system is summarized in Table 1. Analysis of the data was made separately for pre- and post-course performances. Statistically significant changes included the following: increase in vibration in the palmar-dorsal (P-D) direction; increase in drill RPM; increase in drill force; drilling time ($P < 0.01$, pre-mean = 8.28, post-mean = 9.34); reduced frequency of skiving ($P < 0.01$, pre-mean = 22, post-mean = 6); and preparation time ($P = 0.01$, pre-mean = 27.3, post-mean = 9.7). Other notable yet not statistically significant changes (see Table 1 for *P* values) included reduction in over-penetration (28.8-18.2 mm), reduction in skiving (22%-6%), and reduction in preparation time (and total time consequently; 27.3-9.65 seconds).

The approach taken by each resident varied more than expected. Several trials (11 of 75 pre-course, 13 of 69 post-course) were not correctly recorded or were eliminated during the trial analysis owing to some unanticipated movement pattern, which resulted in

Table 1. Bone drilling performance averaged across 25 year-one orthopaedic residents from seven institutions

Variable	***Pre-course scores, average (SD)***	***Post-course scores, average (SD)***	***Pre- vs post-course scores (P value)***
Over-penetration, mm[a]	28.8 (54.8)	18.3 (18.7)	0.322
Toggle in P-D, deg[b]	3.94 (13)	1.40 (0.93)	0.499
Toggle in R-U, deg[b]	30.4 (97.5)	44.3 (118)	0.169
Vibration in P-D, m/s^{2c}	1.76 (0.91)	2.05 (0.75)	0.001
Vibration in R-U, m/^{s2}c	0.7 (0.41)	0.71 (0.48)	0.772
Skiving, %[d]	22 (42)	6 (24)	0.009
Hole angle[e]	1.7 (1.6)	1.4 (1.1)	0.222
RPM, cycles/min[f]	917 (77.2)	944 (72.1)	0.074
Drilling force, N[g]	58.6 (31.8)	84.3 (44.9)	0.004
Total time, s[h]	35.6 (39)	19 (7.97)	0.576
Preparation time, s[i]	27.3 (38.4)	9.65 (6.34)	0.012
Drilling time, s[j]	8.28 (7.04)	9.35 (4.56)	0.002
Pullout force, N[k]	0.94 (0.42)	0.89 (0.39)	0.905

P-D, palmar-dorsal; R-U, radial-ulnar; RPM, revolution per minute.

[a] Maximum distance the drill bit protrudes through the distal surface.

[b] Range of angles in the corresponding plane during drilling (entire hole).

[c] Mean of the values reported from the corresponding axis of the accelerometer (entire hole).

[d] If the subject was observed to skyve while beginning to drill, it was noted by the experimenter.

[e] Deviation from perpendicular, measured retrospectively using a custom goniometer fixture (*X-Z* plane).

[f] Maximum observed during the final four seconds before the drill reaches maximum depth.

[g] Maximum applied force during drilling.

[h] Measured from the time the experimenter provides the instruction to begin until the time they pull out the drill bit.

[i] Measured from the time the experimenter provides the instruction to begin until the drill begins to rotate.

[j] Total time minus preparation time.

[k] Specimens were mounted to a modified angle vise that allowed positioning the screws in line with the test actuator. A cyclically load was then applied using an MTS 858 Mini Bionix II (MTS Systems Corporation, Eden Prairie, MN) frame following a protocol described.[24]

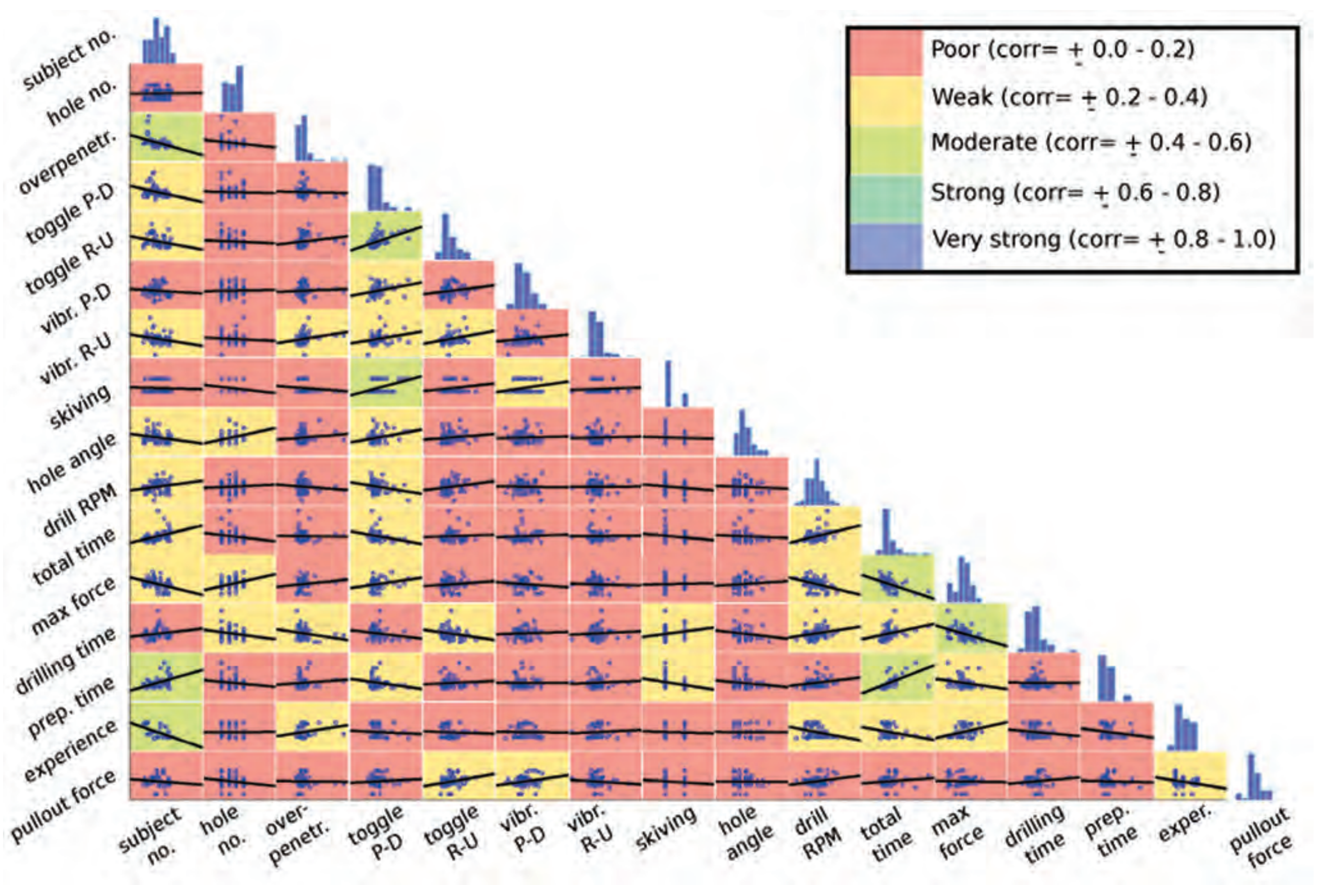


Figure 5. Correlation matrix for the performance parameters measured during the pre-course task. The matrix below shows the correlation between each pair of parameters. Also, scatter plots of the variables are shown after outlier rejection. The slope of the lines in each box is equal to the related correlation coefficient (slope of ±1 equivalent to perfect positive and negative correlation). Histograms of the variables are shown along the matrix diagonal.

a miscalculation of one or more of the 16 measured parameters. Beyond the variables themselves, much can be inferred from their correlations (Figures 5 and 6). First, the strength of correlations between post-course parameters was generally stronger. Notable correlations included over-penetration with drilling force (0.65), P-D toggle (0.65), P-D vibration (0.53), drilling time (-0.41), and drill RPM (-0.36); drilling time with both drill RPM (0.38) and P-D toggle (-0.40); and drilling force with both drill RPM (-0.41) and P-D toggle (0.32).

Effect of reported *Experience Level* on performance was not strongly present in the data. However, this was assessed as a self-reported parameter obtained from the survey ("estimate number of surgeries performed and viewed"); responses range from 40 to 200. Interestingly, none of the residents distinguished between how many procedures viewed versus performed. This may suggests that residents considered those two experiences as equivalent, though it seems clear they would not be from a pedagogical standpoint. The wide range in responses likely reflected various teaching styles between orthopaedic residency programs. Similarly, some non-trivial correlations were observed over *Subject Number.* This ordinal effect is almost certainly coupled to the fact that participants were ordered in groups based on their home institution owing to scheduling convenience.

The survey asked residents to explain their tactics when drilling. Approximately three-quarters of the responses mentioned using full RPM for at least portion of the time and "feeling" for the distal cortex. About half of the responses mentioned listening for a change in pitch associated when reaching the distal cortex. Around a quarter of the responses mentioned beginning normal to the proximal cortex and then acquiring the desired hold angle as needed, changing speed as a function of depth, maintaining target angle (not toggling), and applying less pressure at the distal cortex. Three residents stated that they would "tap" the drill against the distal cortex when they determined to reach it. One resident said that they generally used a slower feed rate throughout the task.

DISCUSSION

In the current study, we quantified the drill performance of residents before and after a motor skills course with use of a custom-made rotary handpiece. Performance parameters with statistically significant changes

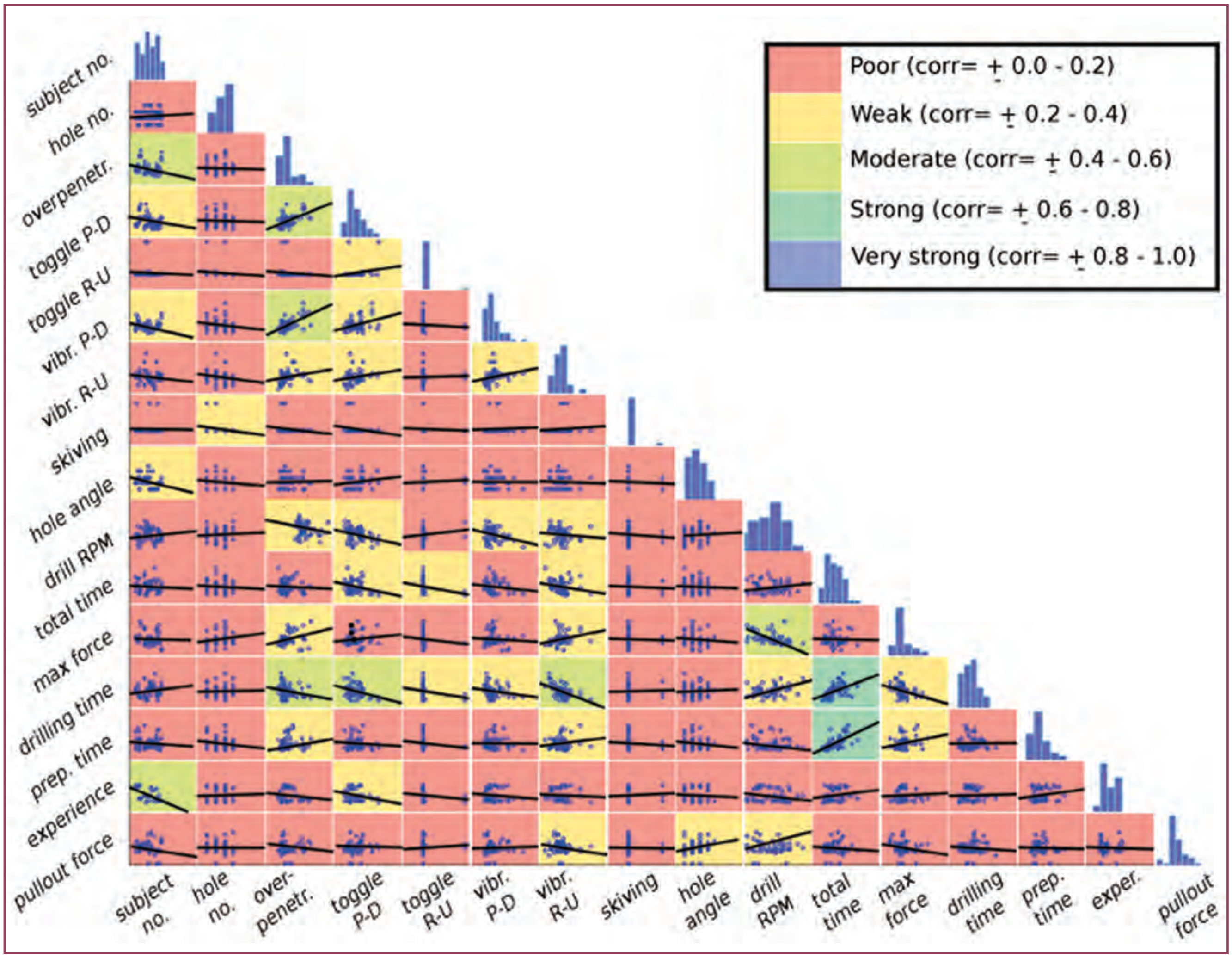


Figure 6. Correlation matrix for the performance parameters measured during the post-course task. The matrix below shows the correlation between each pair of parameters. Also, scatter plots of the variables are shown after outlier rejection. The slope of the lines in each box is equal to the related correlation coefficient (slope of ±1 equivalent to perfect positive and negative correlation). Histograms of the variables are shown along the matrix diagonal.

included drill vibration in the P-D direction, drill RPM, drill force, drilling time, skiving frequency, and preparation time. Because of the intensive r-day motor skills course, which included both didactic and hands-on components, it is no surprise to see evidence of performance improvement in the data. High variability is evident for most of the measured parameters both within and between participants.

Using much larger sample sizes, additional patterns might be observed with statistical significance. A weak trend with associated performance and *Hole Number* suggest that a more careful evaluation of this factor may reveal learning and adaptation on short time scales. The variability observed in the self-reported responses regarding drilling strategy indicates that the residents at SWOTA had different cues and tactics in mind. The role of tactile and auditory feedback may also merit further investigation.

Many inferences can be made regarding the correlations found. From a simple mechanics standpoint, these relationships can be predicted (eg, drilling force with drill vibration and RPM). Similarly, aspects of human motor control (eg, delay associated with proprioceptive feedback) are aligned with correlations between drilling time (with associated force), over-penetration distance, and drill force and toggle. Hypotheses explaining why some changes were observed might be informed by correlations in the data. For instance, an increase in P-D vibration was noted, which may initially seem counterintuitive. However, this parameter is negatively correlated with drilling time in both pre- and post-course trials. The correlations found should be further explored to determine situations in which parameters are fundamentally linked by mechanics, human motor control, and level of training.

The noted correlations (eg, over-penetration with drilling force P-D toggle, drilling time, and drill RPM) may help guide training protocols for orthopaedic residency programs. In future work, we hope to explore the difference in performance that correlates to the residency program. These differences may elucidate critical pedagogical factors. We also hope to decouple the roles of practice and quality of initial instruction in the eventual skills obtained by orthopaedic surgeons.

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