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► **To cite this version:**

Giovanny Arbelaez Garces, David Joseph, Mauricio Camargo, Nguyen Tran, Laure Morel. Contribution to the objective assessment of technical skills for surgery students: An accelerometer based approach. International Journal of Industrial Ergonomics, 2018, 64, pp.79 - 88. <10.1016/j.ergon.2017.12.002>. <hal-01812007>

HAL Id: hal-01812007

<https://hal.univ-lorraine.fr/hal-01812007v1>

Submitted on 29 Mar 2019

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Contribution to the objective assessment of technical skills for surgery students: an accelerometer-based approach

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Abstract:

Aim of study: Gestural skills assessment in odontology is a highly complex task. Although mandatory for certification, proficiency assessment is still required for parameters that are more objective. Our aim was to assess whether accelerometer sensors might contribute to distinguishing efficiency in therapeutic gesture from experts and novices in the realization of surgical sutures.

Material and method: 3 groups of participants: novices (n = 8), intermediaries (n = 14) and experts (n = 7) were enrolled in the study. They had to perform different types of odontological suture. We used 2 wireless wrist sensors to measure objectively the acceleration of both hands and to deduce the economy and the fluidity of the movement. A video recording was also used to complete the assessment.

Results: The time and motion criteria were documented to significantly correlate with the experience of the participant. The total time factor has a significant effect with the experience level (p = 0.006). The fluidity of the movement has also been shown to vary significantly between groups.

Conclusion: The use of accelerometers coupled with image analysis could make it possible to envisage in the long run an objective evaluation for this type of surgical gesture.

Keywords: Objective assessment, basic skills, suturing, dental pedagogic strategy, accelerometers

1. Introduction

The use of simulators and inanimate models for surgical training has slowly spread in training institutions around the world during the last ten years. Simulators allow trainers the freedom to assess and manage the complexity of the clinical scenario for students without risking patients' safety (Acton, 2015). The emergence of these technologies has not only revolutionized the training of surgical skills, but the assessment of surgeons in these techniques has become an important concern (Pellegrini, 2012). Moreover, being able to objectively assess surgeons' technical skills has become an important research topic and a principal concern for surgical training.

Most screen-based simulators allow direct assessment of gesture and enable immediate feedback. However, for other types of technologies such as inanimate models, an expert surgeon performs the assessment. Traditional skill assessment is subjective to the evaluator and can be influenced by several factors. To limit this problem, different strategies have been implemented, such as OSCE (objective structured clinical evaluation) (Scott, Evans, Drummond, Mossey, & Stirrups, 2001), analysis, videos, and more recently haptic simulation (Joseph et al., 2014). This highlights the need for a more objective assessment (Shaharan, 2014). The aim of this paper is thus to propose a method for objective surgical skills assessment using motion sensors.

(Datta, Mackay, Mandalia, & Darzi, 2001) proposed using motion-tracking analysis to objectively measure surgical skills. Their study suggested that hand motion analysis can be an effective objective

48 measure of dexterity. However, their study focused only on quantity of hand movements and time to
49 complete the task. (Sánchez et al., 2014) proposed a method of evaluating laparoscopic skills using
50 accelerometers. However, their work only focused on economy of movement criteria. In order to
51 assess the complexity of the surgical skills put into practice during a procedure, several criteria need
52 to be assessed, some of which might not be covered by motion sensors. In this paper, the complexity
53 of surgical skills assessment is covered by completing the motion sensor data with criteria from an
54 OSCE (Hanson, Mossey, & Macluskey, 2010; Niitsu et al., 2013). To validate the use of motion
55 sensors (accelerometers) as a new objective evaluation strategy, we put in place a preliminary
56 prospective study at the Nancy-Lorraine Surgery School. The study allowed us to check whether there
57 is a relationship between the measurements made by motion sensors and a subjective evaluation when
58 performing a basic surgical procedure in dentistry (sutures). A mixed method integrating objective
59 and subjective criteria was then proposed and validated. The results obtained were then compared
60 with the traditional OSCE based evaluation method.

61

62 The remainder of the paper is structured as follows: Section 2 presents an overview of research related
63 to surgical skill assessment and particularly on the usage of accelerometers. Section 3 describes
64 materials and methods used in the study. Sections 3.2 present the results, which are then discussed in
65 Section 4. Section 5 presents the conclusions of the paper.

66

67 **2. Related research**

68 **2.1. Surgical training and skills assessment**

69 According to Fitts and Posner's theory of motor skill acquisition, it is divided into three stages (Fitts
70 & Posner, 1967). The first stage is cognition; in this stage the learner is shown the basic elements of a
71 surgical intervention, making a knot for example. The learner must understand the mechanics related
72 to the skill, the way to move the hands, take the fill, etc. With practice, the learner goes through the
73 integration stage; he becomes able to execute the task in a fluid manner with few interruptions. Then,
74 in the automation stage, the activity is not only fluid but is carried out with almost no errors. When
75 applied to surgical training, the first two steps of this model can be done without prior contact with
76 patients through the acquisition of the basic skills of the surgical technique.

77

78 Despite technological advances, surgical education has remained almost unaltered for over a century.
79 The "see one, do one, teach one" model, which until a few years ago was offering good results, is
80 limited by the availability of expert surgical physicians, by the diversity of procedures, the amount of
81 patients available and, more importantly, by the need to maintain patient safety (Morris, 2005). There
82 are many surgical training devices that can be used in the learning process: inanimate models, virtual
83 reality, synthetic and cadaveric animal models, as well as real patients for education of critical
84 incidents (Acton, 2015; R. K. Reznick & MacRae, 2006). Some of these models are very expensive
85 and some have limited availability. Using animals is difficult because of ethical concerns, high cost,
86 and the need for special equipment. On the other hand, inanimate synthetic models are portable,
87 reliable, and a little less expensive than earlier varieties.

88

89 Inanimate models are, however, at a disadvantage compared to virtual simulators because the latter
90 allow us to directly assess the technical skill of the student without the intervention of an expert
91 trainer. In order to objectively evaluate skills, performance verification lists or OSATS (Objective
92 Structured Assessment of Technical Skills) are commonly used (R. Reznick, Regehr, MacRae,
93 Martin, & McCulloch, 1997). However, the use of OSATS requires the implication of an experienced
94 practitioner as judge. Technological tools could be used to assess some skill parameters and can
95 become complementary to the objectivity of the evaluator (R. K. Reznick & MacRae, 2006).

96

97 One of the challenges in skill assessment is to choose which parameters to measure (van Hove,
98 Tuijthof, Verdaasdonk, Stassen, & Dankelman, 2010). Hand movement analysis allows measurement

99 of motricity and dexterity (Mason, Ansell, Warren, & Torkington, 2013). In surgical skill assessment,
 100 this analysis can easily be performed with a motor sensor or accelerometer (D'Angelo et al., 2015).
 101 Three parameters have mainly been used in studies concerning surgical skills: time, economy of
 102 movement, and path length. Table 1 summarizes the main studies concerning movement analysis in
 103 surgical skills assessment and the parameters that were used.

104 **Table 1. Movement analysis metrics used for surgical skills assessment.**

| Reference | Conceptual validation | | |
|---|-----------------------|---------------------|-------------|
| | Time | Economy of movement | Path Length |
| (Datta et al., 2001) | Yes | No | Yes |
| (Aggarwal et al., 2007) | Yes | Yes | Yes |
| (Datta, Chang, Mackay, & Darzi, 2002) | Yes | Yes | Non-treated |
| (Brydges, Classen, Larmer, Xeroulis, & Dubrowski, 2006) | Yes | Yes | Non-treated |
| (Brydges, Sidhu, Park, & Dubrowski, 2007) | Yes | Yes | Non-treated |
| (Smith, Torkington, Brown, Taffinder, & Darzi, 2002) | Yes | Yes | Yes |
| (Moorthy et al., 2004) | Yes | Non-treated | Yes |
| (S. D. Bann, Khan, & Darzi, 2003) | Yes | Yes | Non-treated |
| (Brydges et al., 2006) | Yes | Yes | Non-treated |

105

106 2.2. Assessment metrics

107 The metrics for assessing surgical skills performance can be divided into two categories: efficiency
 108 metrics and quality metrics (Fried & Feldman, 2008). Efficiency metrics are measurable physical
 109 parameters, requiring the use of motion devices to be acquired. They are objective, reproducible, and
 110 not prone to misinterpretation. An efficiency metric should not only provide information about the
 111 intervention, but also help to identify key success and failure factors, in addition to being able to
 112 distinguish an expert from a novice (Oropesa et al., 2011). Quality metrics concern the definition and
 113 execution of a task; they are parameters that cannot be quantified – for example, knowledge of the
 114 procedure, final outcome of the intervention, knowledge of instrument handling, etc. Table 2 and
 115 Table 3 summarize the most commonly used metrics to discern the surgeon's experience.

116 **Table 2. Efficiency metrics for surgical skills assessment.**

| Efficiency metrics | Description | Units |
|--------------------|--|------------------|
| Time | The time needed to complete an intervention. It's commonly related to surgical skills. The greater the experience in the intervention, the less time it takes to complete. | <i>min, sec</i> |
| Path Length | The cumulative distance based on tool movement during the intervention. It is also commonly related to the surgeon's precision. | <i>m, cm, mm</i> |

| | | |
|----------------------------------|--|-------------------------|
| Jerk | These are sudden movements resulting in changes in the acceleration. | $\frac{m}{sec^3}$ |
| Speed | The speed of change of position of the instruments per second. | $\frac{m}{sec}$ |
| Economy of movement (MOE) | Execution of the intervention with a limited number of movements. It is defined as the total number of hand movements per second (S. Bann, Darzi, Munz, Kumar, & Moorthy, 2004). | $\frac{movements}{sec}$ |

117

118 **Table 3. Quality metrics for surgical skill assessment.**

| Quality metrics | Description |
|---------------------------------|--|
| Results | Analysis of the intervention outcome |
| Errors | Number of errors during the intervention |
| Instrument handling | Proper knowledge and use of the instruments during the procedure |
| Knowledge of specific procedure | Knowledge of the entire procedure |

119

120 It appears that using a single type of metric to evaluate the surgeon's skills is not enough, but the
 121 assessment must be a combination of the two types (Fried & Feldman, 2008). Using only one of the
 122 metrics mentioned above may be misleading; for example, in the case of a suture, the time required to
 123 complete the task is irrelevant if the point does not approach the tissue correctly or the node is poorly
 124 executed. For these reasons it is advised to use the two types of metrics (Ponton-Carss, Kortbeek, &
 125 Ma, 2016).

126

127 As seen from the previous tables, efficiency metrics require the use of different technologies to be
 128 evaluated. Accelerometers and motion analysis have been used in the evaluation of the next section,
 129 which discusses some of the existing works.

130

131 **2.2.1. Motion analysis usage**

132 The use of motion-tracking analysis to assess surgical skills has already been proposed by (Datta et
 133 al., 2002, 2001) using electromagnetic devices and video analysis of hand movement. Their study
 134 suggested that hand motion analysis can be an effective objective measure of dexterity. However,
 135 their study focused only on quantity of hand movements and time to complete the task. (Sánchez et
 136 al., 2014), on the other hand, proposed assessing laparoscopic skills using low-cost accelerometers
 137 similar to those present in smartphones, though their work was restricted to the assessment of
 138 economy of movement criteria.

139 Most of the existing works have focused on laparoscopic interventions that have a reduced field of
 140 motion. While a correlation between OSATS and motion analysis assessments had already been
 141 shown (Datta et al., 2001), in order to assess the complexity of the surgical skills put into practice
 142 during a procedure several criteria need to be assessed, some of which might not be covered by
 143 motion sensors only. To the best of our knowledge, there is no proposal for surgical skill assessment
 144 done with OSATS guides and motion tracking. For this reason, in this paper we present a proposal to
 145 assess surgical skills combining accelerometers and standardized assessment guide.

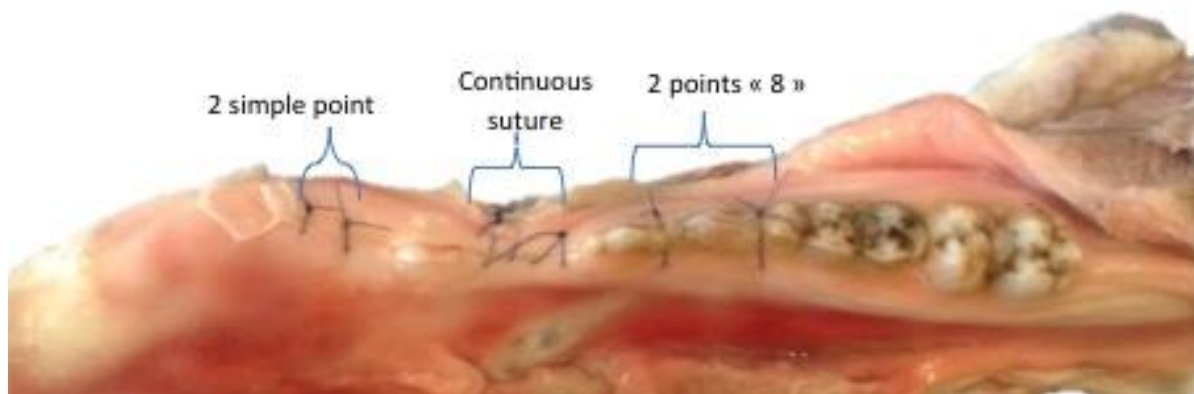
146 3. Towards an objective surgical skills assessment

147 In order to propose an objective assessment using an accelerometer, it was first necessary to verify the
148 relevance of using the accelerometer to differentiate the experience level of the participants in the
149 study, then to verify if it can be used as an assessment tool and to use it to compare the results with an
150 assessment performed by an expert evaluator (traditional method). The proposed study is presented in
151 the next section.

152 3.1. Materials and methods

153 **General study design:** This study was conducted at the School of Surgery of Nancy, *Université de*
154 *Lorraine* in France. In total, 29 participants were recruited from the school's faculty of dentistry, and
155 three groups per experience level were formed: "experienced" (n=7), "intermediate" (n=14) and
156 "novice" (n=8). Experienced practitioners formed the first group, with a focus on oral surgery,
157 periodontics, and implantology. The intermediate group consisted of 6th year dentistry students, while
158 individuals without any dental surgery practice formed the novice group.

159
160 **Exercise protocol:** All participants receive a theoretical instructional form indicating the procedures
161 to be performed. Each participant is asked to perform: 2 Single 0 points, 2 points in 8 and a single
162 running suture with 4 passes of the needle on the lower jaw of a pig, the flaps of which are retracted
163 prior to the operation (c.f. Figure 1).



164
165 **Figure 1. Protocol exercise suture points.**

166
167 **Motion Sensors:** Two wireless motion sensors (Captiv T-sense, Tea®, Nancy), placed in the
168 participant's wrist, were used to record the hand acceleration in the 3 axes of movement (x,y,z) at a
169 frequency of 128 Hz. The sensors were fixed at the participants' wrists at the beginning of the
170 exercise, the X-axis pointing to the back of the participant.

171
172 **Procedure:** Each participant is equipped with the motion sensors and then they are asked to perform
173 the exercises from the protocol (suture points).

174 For standardized procedures, the distance between the elbow and the floor of the participants is
175 identical for all subjects (94 cm).

176 Each operator is filmed anonymously throughout the completion of the procedure using a camcorder
177 (Everio GS TD1, JVC).

178 Instrumentation available to achieve the sutures is identical for all participants and includes:

- 179 • Flexocrin 4.0 wire (Braun®)
- 180 • Castroviejo Clamp
- 181 • Surgical scissors
- 182 • Surgical tweezers

183 At the end of the procedure, a picture of the work is also taken and used to complete the evaluation of
 184 the participants.

185 Recording is started and stopped with the participants' hands lying flat on the table. This is a
 186 reference in terms of acceleration for the beginning and the end of the test.

187 **Study of subjective skills:** In order to have a reference evaluation of each subject's performance to
 188 compare with the information collected by the motion sensors, all the videos are broadcast on a
 189 private "youtube" link to be single blind evaluated by an experienced practitioner. Each video is
 190 evaluated by the practitioner on five criteria with a score from 1 to 5: *Respect of tissues, Time and*
 191 *movement, Instrument handling, Operation flow, and Knowledge of the procedure.* The score for each
 192 participant ranges between 5 and 25 points. The evaluation criteria used in the expert assessment were
 193 taken from the Hanson study of 2010 (Hanson et al., 2010), which we have completed with those of
 194 Nitsu et al. (Niitsu et al., 2013). Table 4 shows the scale used during the assessment for each criterion.

195

196 **Table 4. Evaluator assessment scale.**

| Respect of tissue | | | | |
|---|---|--|---|---|
| 1 <i>Frequently used unnecessary force on tissue or caused damage by inappropriate use of instruments</i> | 2 intermediate situation | 3 <i>Careful handling of tissue but occasionally caused inadvertent damage</i> | 4 intermediate situation | 5 <i>Consistently handled tissue appropriately with minimal damage</i> |
| Time and motion | | | | |
| 1 <i>Many unnecessary moves</i> | 2 intermediate situation | 3 <i>Efficient time/motion but some unnecessary moves</i> | 4 intermediate situation | 5 <i>Clear economy of movement and maximum efficiency</i> |
| Instrument handling | | | | |
| 1 <i>Repeatedly makes tentative or awkward moves with instruments by inappropriate instrument</i> | 2 intermediate situation | 3 <i>Competent use of instruments but occasionally appeared stiff or awkward</i> | 4 intermediate situation | 5 <i>Fluid moves with instruments and no awkwardness</i> |
| Flow of operation | | | | |
| 1 <i>Frequently stopped operating and seemed unsure of next move</i> | 2 intermediate situation | 3 <i>Demonstrated some forward planning with reasonable progression of procedure</i> | 4 intermediate situation | 5 <i>Obviously planned course of operation with effortless flow from one move to the next</i> |
| Knowledge of specific procedure | | | | |

| | | | | |
|---|-----------------------------------|--|-----------------------------------|---|
| 1 | 2 | 3 | 4 | 5 |
| <i>Deficient knowledge. Needed specific instruction at most steps</i> | intermediate situation | <i>Knew all important steps of operation</i> | intermediate situation | <i>Demonstrated familiarity with all aspects of operation</i> |

197

198 **Objective analysis of operation flow and economy of movement:** From the acceleration data
 199 provided by the motion sensors, it was possible to calculate the standard speed of the overall
 200 operation and by integrating it, a distance indicator (path length) linked to the global motion is
 201 obtained. This criterion reflects if there is an economy of movement in comparison with other
 202 candidates and can be directly compared with the “*time and movement*” criteria of the subjective
 203 evaluation.

204 To objectively assess the “*operation flow*” we used the total acceleration; then, using conditional
 205 formatting in R, a rating of 1 to 5 could be given to each participant for these two parameters. A
 206 detailed explanation of the calculations is given in the following section.

207 **Statistical analysis:** The results were expressed as mean \pm standard deviation from the mean (m \pm
 208 SEM). A one factor ANOVA or t-test two-tailed *t* was used to compare performance between groups.
 209 The frequency analyses were made using the Fischer test. Probability $P < 0.05$ was considered
 210 statistically significant. For the pairs that showed a significant correlation a post-hoc HSD Tukey test
 211 was used. Analyses were made using the R language (R Foundation for Statistical Computing,
 212 Vienna, Austria) and RStudio (RStudio inc., Boston, MA, USA).

213 3.2. Results

214 3.2.1. Expert assessment of each participant video using the evaluation grid

215 The total scores obtained by participants range from 5-23 on a scale from 5 to 25 (cf. Table A.7). The
 216 *average scores* ranged from 14.58 ± 1.459 for the "Novice" group, 21.67 ± 0.5578 for the
 217 "Experienced" group, and 16.80 ± 0.8667 for the "Intermediate" group.

218 Regarding the *Respect of tissue* criterion, the "Intermediate" group gets an average of 3.0 ± 0.326 , the
 219 "Novice" group gets 3.8 ± 0.1333 , and the "Experienced" group gets the best average with $4.333 \pm$
 220 0.2108 . The differences are significant between the "Experienced" and "Intermediate" groups and
 221 between the "Experienced" and "Novice" groups.

222 In the *Economy of movement* criterion the "Novice" group gets an average of 2.917 ± 0.358 , the
 223 "Intermediate" group gets a higher score with 3.20 ± 0.24 , and the "Experienced" Group stands out
 224 with a better average of 4.333 ± 0.2108 .

225 Average scores for the *Instrument handling* criterion ranges from 2.667 ± 0.284 for the group
 226 "Novice" to 4.333 ± 0.2108 for the group "Experienced", the "Intermediate" group getting an average
 227 score of $3,100 \pm 0, 2769$.

228 *Flow of operation* that also was objectively assessed by the sensors is denoted by an average
 229 subjective assessment of 3.083 ± 0.3128 for the "Novice" group, 3.20 ± 0.200 for the "Intermediate"
 230 group and 4.333 ± 0.2108 for the "Experienced" group.

231 Finally, the *Knowledge of specific* procedure criterion is estimated to average 2.917 ± 0.313 for the
 232 "Novice" group, 3.50 ± 0.3073 for the "Intermediate" group, and 4.333 ± 0.211 for the "Experienced"
 233 group.

234 3.2.2. Validation of the accelerometer as a differentiation tool

235 As previously explained, in order to validate the results it was first necessary to identify whether the
 236 accelerometer data could be used to distinguish between the expert and novice subjects. The
 237 following hypotheses were tested:

238 H1: Maximal accelerations in X, Y, Z axes and standard deviations are minimal and inversely related
 239 to the subject's experience.

240 H2: The cumulative acceleration during the procedure is inversely related to subject experience.
 241 H3: Total procedure time is inversely related to subject experience (least time denotes more
 242 experience).

243 Table 5 shows the parameters that were calculated from the accelerometer data to be used in the
 244 analysis. The mean, maximal and deviation parameters corresponds to statistical features and the
 245 others are domain specific features to motion analysis. The path length feature in particular has been
 246 shown to be an important feature in surgical skill assessment (see Table 1 and Table 2). It is defined as
 247 $Path\ Length = \sum_{i=0}^{n-1} |p_{i+1} - p_i|$; since acceleration is the variation of speed over time, it is
 248 necessary to proceed to a double integration of the value in order to obtain the position eq.1 $P_t =$
 249 $\int \int a (dt) dt$. In this work we used the trapezoidal rule for the numerical integration with the data
 250 from the sensor.

251 **Table 5. Movement analysis parameter definition.**

| Parameter | Description | Formula |
|---|--|--|
| Acceleration | | |
| Resulting acceleration (a) | Calculated using the Pythagoras theorem, where x, y, z represent the acceleration on each axis. | $a = \sqrt{x^2 + y^2 + z^2}$ |
| Total resulting acceleration (AT) | The addition of the resulting accelerations. | $AT = \sum_{i=0}^n a_i$ |
| Maximal acceleration x-axis, y-axis, z-axis | The maximal acceleration in each axis i ($i = x, y, z$) | $a_{\max i} = \max\{a_i\}$ |
| Mean resulting acceleration (\bar{a}) | The mean of the resulting acceleration | $\bar{a} = \frac{1}{n} \sum_{i=0}^n a_i$ |
| Mean acceleration x-axis, y-axis, z-axis | The mean acceleration on each axis i ($i = x, y, z$) | $\bar{a}_i = \frac{1}{n} \sum_{j=1}^n a_{ij}$ |
| Standard deviation acceleration x-axis, y-axis, z-axis ($\sigma_{a,i}$) | The standard deviation for the acceleration on each axis i ($i = x, y, z$) | $\sigma_{a,i} = \sqrt{\frac{\sum_{j=1}^n (a_i - \bar{a}_i)^2}{N}}$ |
| Path Length | The cumulative hand distance based on tool movement during the intervention. | $Path\ Length = \sum_{i=0}^{n-1} p_{i+1} - p_i $ |
| Time | Calculated using the motion sensor from the moment the hands leave the initial position until the procedure is completed and the hands return to the initial position (flat hands on the table). Sensor frequency is 128 Hz. | |

252
 253 Table 6 summarizes the data analysis results. Results are presented as Mean (M) \pm Standard Deviation
 254 (SD). For the maximal acceleration, mean acceleration, SD acceleration no significant difference was
 255 found among the groups except for the SD acceleration x-axis for the dominant hand. However, there
 256 was a more significant difference between the groups for the Total resulting acceleration, the Total
 257 time and Total path length for both hands.

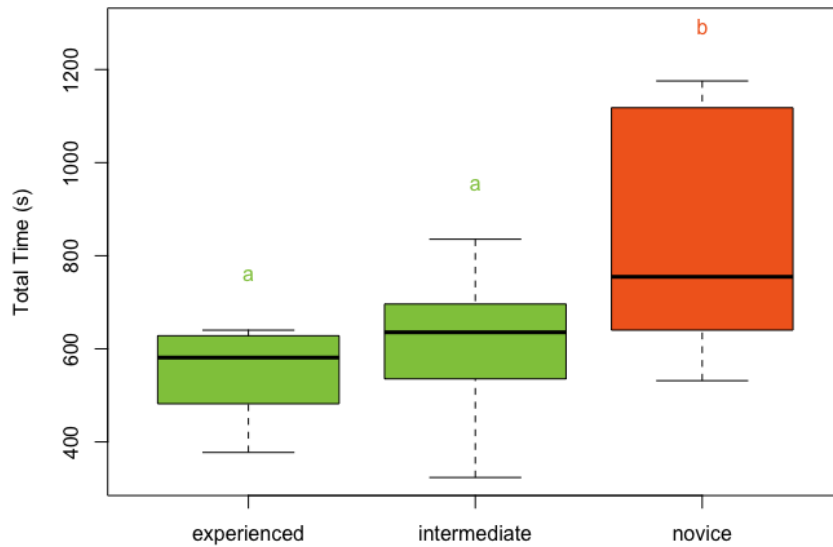
| | Expert | Intermediate | Novice | P |
|------------------------------|---------------------|---------------------|----------------------|----------|
| | M ± SD | M ± SD | M ± SD | |
| Total Time | 545.524 ± 100.263 | 610.395 ± 148.388 | 841.609 ± 257.819 | 0.006 * |
| Dominant hand | | | | |
| Max. Acceleration x-axis | 0.922 ± 0.320 | 0.838 ± 0.268 | 0.962 ± 0.121 | 0.516 |
| Max. Acceleration y-axis | 0.665 ± 0.269 | 1.210 ± 0.707 | 1.080 ± 0.540 | 0.152 |
| Max. Acceleration z-axis | 1.187 ± 0.103 | 1.038 ± 0.239 | 1.096 ± 0.274 | 0.379 |
| SD Acceleration x-axis | 0.212 ± 0.076 | 0.229 ± 0.047 | 0.190 ± 0.039 | 0.277 |
| SD Acceleration y-axis | 0.270 ± 0.057 | 0.294 ± 0.065 | 0.311 ± 0.062 | 0.459 |
| SD Acceleration z-axis | 0.350 ± 0.041 | 0.376 ± 0.046 | 0.354 ± 0.078 | 0.504 |
| Mean Acceleration | 9.580 ± 0.028 | 9.627 ± 0.093 | 9.610 ± 0.037 | 0.370 |
| Total Path Length | 45.7 ± 23 | 85.7 ± 64.1 | 141 ± 110.3 | 0.058** |
| Total resulting Acceleration | 668940.8 ± 122743.6 | 751934.7 ± 181201.9 | 1035054.1 ± 316235.4 | 0.005* |
| Non-dominant hand | | | | |
| Max. Acceleration x-axis | 0.784 ± 0.129 | 4.963 ± 15.623 | 0.883 ± 0.214 | 0.609 |
| Max. Acceleration y-axis | 1.944 ± 0.289 | 1.565 ± 0.512 | 2.065 ± 0.618 | 0.072 |
| Max. Acceleration z-axis | 1.185 ± 0.214 | 5.563 ± 16.775 | 1.238 ± 0.401 | 0.620 |
| SD Acceleration x-axis | 0.168 ± 0.038 | 0.236 ± 0.072 | 0.191 ± 0.042 | 0.041 |
| SD Acceleration y-axis | 0.241 ± 0.052 | 0.274 ± 0.086 | 0.294 ± 0.064 | 0.384 |
| SD Acceleration z-axis | 0.402 ± 0.039 | 0.403 ± 0.087 | 0.381 ± 0.073 | 0.787 |
| Mean Acceleration | 9.885 ± 0.079 | 9.888 ± 0.102 | 9.920 ± 0.095 | 0.708 |
| Total Path Length | 45.2 ± 16.8 | 72 ± 65.9 | 138.1 ± 148.9 | 0.13*** |
| Total resulting Acceleration | 689721.1 ± 123852.3 | 771648.4 ± 184466.6 | 1070392.7 ± 334148.7 | 0.005* |

Data are presented as Mean ± Standard deviation (M ± SD)
* $P < 0.001$, ** $P < 0.01$, *** $P < 0.1$ Statistically significant

259

260 In order to verify the relationship between the variables that presented a significant difference (Total
261 time, Total resulting acceleration and Total path length) an analysis using an HSD Tukey test was
262 performed.

263 The Total time factor presented a significant effect with the experience level ($p = 0.006099$). The
264 “experienced” group ($M = 545.52 \pm 100.2$ s) performs the exercise in less time than the
265 “intermediate” ($M = 610.39 \pm 148.38$ s) and “novice” group ($M = 841.60 \pm 257.81$ s). The analysis
266 shows that the more experienced the candidate, the less time is required to perform the intervention in
267 validation of the H3 hypothesis. Tukey’s test showed that there is a significant difference between the
268 “experienced” and the “novice” groups. Figure 2 presents the repartition of the data between total
269 time and experience level.

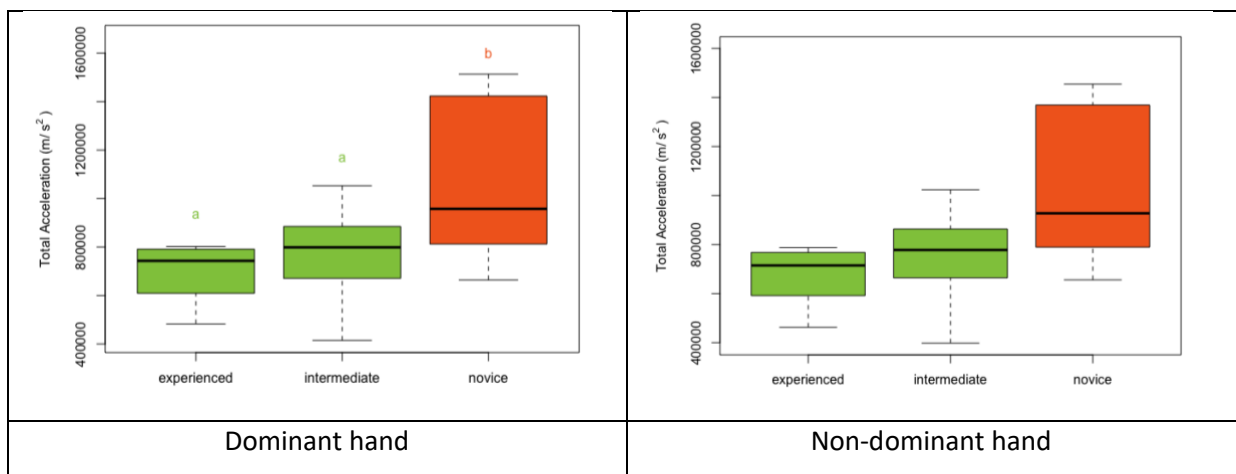


270

271 **Figure 2. Total time per experience level.**

272 In the case of the Total resulting acceleration, the statistical analysis showed that there was a
 273 significant relationship between the experience levels in each hand ($p=0.005$) for the dominant hand
 274 and ($p=0.005$) for the non-dominant hand. There is almost no difference between the hands; the
 275 “experienced” group presented a lower total acceleration than the other groups. This validates the H2
 276 hypothesis that the least experienced participant has the highest total acceleration. Figure 3 shows the
 277 relationship between the total resulting acceleration and the experience levels. The Tukey test showed
 278 that there is an important difference between experienced and novice groups.

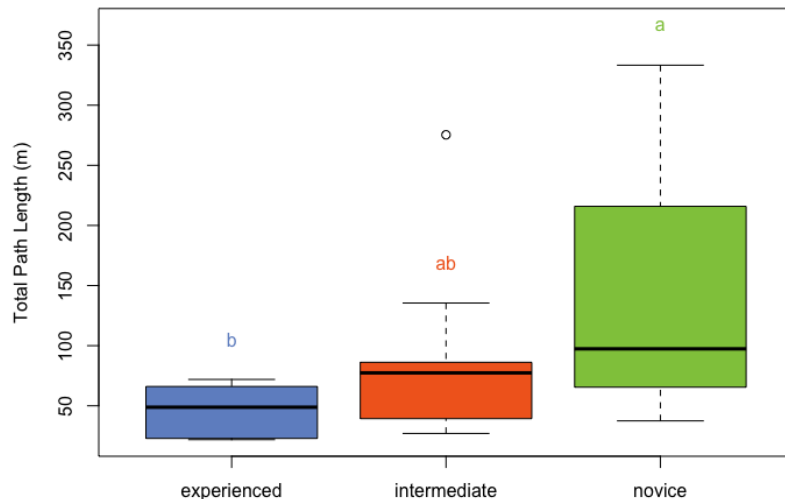
279



280 **Figure 3. Total acceleration per experience group for both hands.**

281 Finally the Total path length showed a significant difference ($p=0.058$) between experience levels for
 282 the dominant hand sensors. The “experienced” group presented a small Total length with the hands
 283 than the “novice” group this implies as in the literature that experienced practitioners had a better
 284 economy of movement. A Tukey analysis was performed; Figure 4 presents the groups’ values,
 285 showing that there is an important difference that allows us to distinguish between “novice” and
 286 “experienced” groups.

287



288

289 **Figure 4. Total length distribution per experience level for dominant hand.**

290 The analysis allowed us to validate the H2 and H3 hypotheses, but there was no significant difference
 291 between the maximal accelerations for each group, so there was insufficient evidence to validate the
 292 H1 hypothesis.

293 **3.2.3. Test of the accelerometer as an objective technical skills assessment tool**

294 Once the relationship between the motion sensor measurements and the levels of expertise had been
 295 validated, we proceeded to use those measurements as part of a skill assessment. The traditional
 296 assessment is based on the evaluation grid shown in Table 4. According to the literature, two of these
 297 five criteria can be assessed using motion analysis features (Datta et al., 2001; Godfrey, Conway,
 298 Meagher, & ÓLaighin, 2008; Sánchez et al., 2014).

299 The *Time and motion* criterion has been shown to correlate with the experience of the subject (cf.
 300 Table 2 metrics). According to its definition, it corresponds to the *total path length* of hand movement
 301 during the procedure.

302 The second criterion corresponds to the *flow of operation*; it has been shown that the number of
 303 movements and *total acceleration* are significant differentiation factors between groups (Saleh, 2008).

304 **3.2.4. Objective grade generation**

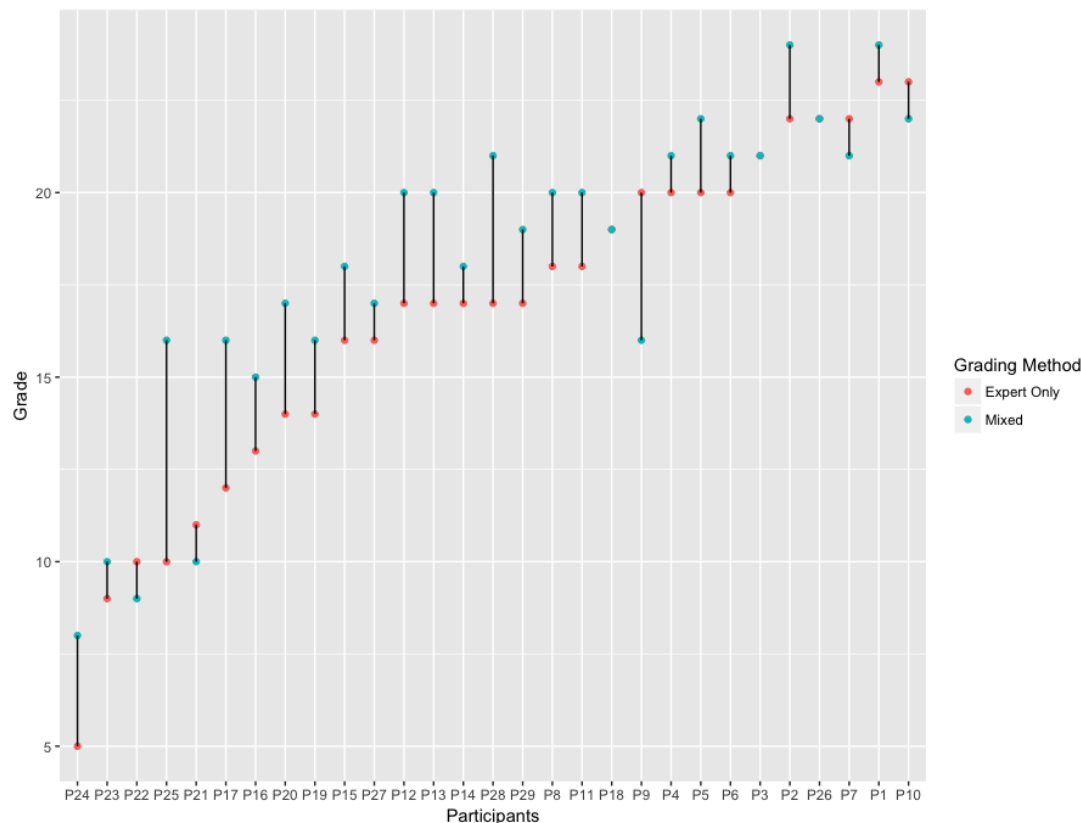
305 In order to compare the two assessment methods, the results obtained by the motion sensor were
 306 expressed in terms of an assessment grade (1-5). For this a five-level interval was created for each
 307 evaluated criterion (Total resulting acceleration and Path Length); the maximum and minimum values
 308 measured are used to create the intervals and then each participant is assigned a grade for each
 309 criterion. Finally, each participant's overall assessment grade (cf. Table A.7) was obtained by
 310 replacing the two criteria motion sensor grades with the evaluator grades, that is to say that the new
 311 grade in the mixed method is composed of the three grades by the evaluator (*Respect of tissue*,
 312 *Instrument handling*, and *Knowledge of specific procedure*) and the two grades generated with the
 313 motion sensors (*flow of operation* and *time and motion*). The grades corresponding to the Flow of
 314 operation criteria range from 4.43 ± 0.53 for the "experienced" group, 3.71 ± 0.72 for the "intermediate"
 315 group, and 2.50 ± 1.30 for the "novice" group. For the Time and motion criteria the grades range from
 316 5 ± 0 for the "experienced" group, 4.50 ± 1 for the "intermediate" group, and 3.75 ± 1.75 for the "novice"
 317 group.

318

319 **4. Discussion**

320 **4.1. Comparison between the evaluator only assessment and the mixed assessment**
321 **(motion sensor included)**

322 Results of both assessment methods were compared (cf. Table A.7). Figure 5 presents the results for
323 each participant's grade obtained by each of the two methods (only the grades with the dominant hand
324 are illustrated). The red dots represent the evaluator's assessment notes, and the blue dots the
325 proposed mixed method using the motion sensors.

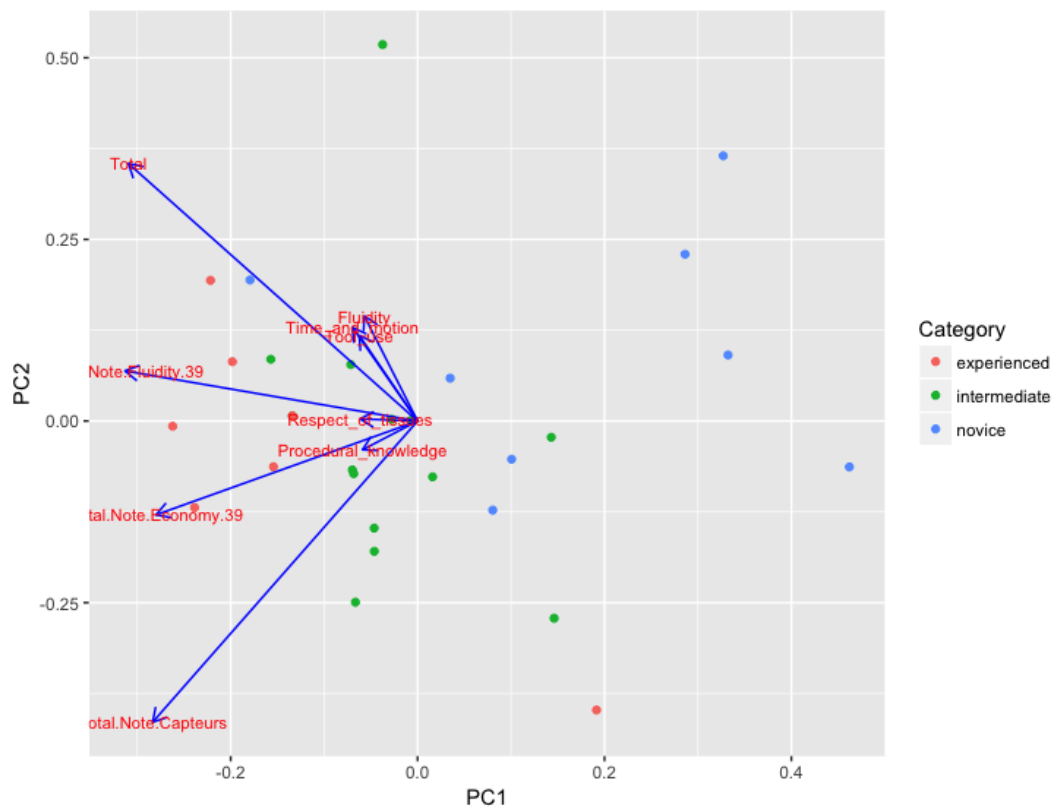


326

327 **Figure 5. Evaluator and mixed assessment grades per participant.**

328 We can observe that the grades follow the same trend, with only a few cases having a big dispersion.
329 In comparison with the expert only evaluation, the mixed method has a precision of 72.4%. It is
330 interesting to note that there are some participants who were initially declared in one category but in
331 the end performed differently; in this case the grades from the mixed method and the evaluator were
332 consistent. For example, a participant was declared as experienced but performed very poorly and was
333 judged by the expert and the mixed method as a novice. We established that this person said it felt
334 uncomfortable with the use of the tool in the experiment because he commonly used another type of
335 tool.

336 In order to analyze the correlation among the assessment criteria a principal component analysis,
337 PCA, was applied. Figure 6 presents a biplot chart; we can observe that all the criteria and, more
338 importantly, the Evaluator only grade (Total) and the Mixed grade (T.Note.Capteurs) follow the same
339 direction. Expert and intermediate participants are mostly located in the left quadrants, with the
340 exception of the expert who performed badly. The novice categories are dispersed in the right
341 quadrant.



342

343 **Figure 6. Principal Component Analysis biplot chart.**

344 **4.2. General discussion**

345 Mastery of gestures and knowledge of procedures are essential to ensure maximum efficiency and
 346 safety for the patient in oral surgery and other surgical disciplines. The evaluation of skills for
 347 surgical procedures in dentistry is frequently based on a subjective assessment using qualitative
 348 criteria. To overcome this problem, various means can be implemented, such as using motion sensors.
 349 In laparoscopic surgery, sensors were successfully used to differentiate between several groups of
 350 practitioners (Salamo et al., 2014; Sánchez et al., 2014), and development of simulators with haptic
 351 technology also allows us to consider an objective assessment of future surgeons' skills (Botden,
 352 Torab, Buzink, & Jakimowicz, 2008; Dehabadi, Fernando, & Berlingieri, 2014; Joseph et al., 2014;
 353 Uemura et al., 2015). Other methods, such as tracking eyes, were also able to differentiate
 354 practitioners of different levels (Richstone et al., 2010). Finally, the use of grid corrections such as
 355 those used in the OSCE (objective structured clinical evaluation) reduces subjectivity without deleting
 356 it completely (Hanson et al., 2010; Niitsu et al., 2013; Scott et al., 2001).

357 The objective assessment of skills is essential in seeking certification of gesture with the ultimate goal
 358 of increasing patient safety (Grigoresco, Mignon, & Tesniere, 2014). Like laparoscopic surgery and
 359 robotic surgery, skills in oral surgery must be considered from the angle of economy of movement,
 360 which reflects a certain skill of the operator. In this study we were able to differentiate between
 361 experts and novices through the subjective evaluation of the procedure videos.

362 The different criteria used allowed us to classify novices and experienced practitioners. In accordance
 363 with what has been shown in robotic surgery (Perrenot et al., 2012), the group of experienced
 364 practitioners showed significantly greater economy of movement than the novice group. It therefore
 365 seems interesting to find a way to measure this parameter objectively. This is what was done in this
 366 study with the use of motion sensors. The results obtained, thanks to the use of sensors, allowed us to
 367 see a marked improvement in the experienced group compared to other groups.

368 We also wanted to objectively define the fluidity of the operation that characterizes the ability of the
 369 practitioner. To do this we calculated the total resulting acceleration during the procedure measured
 370 by the sensors. It was shown that the mixed grades provided by the sensors are as good as the grades
 371 provided by the evaluator.

372 In this study we used sensors attached to participants' wrists to avoid hindering their performance
 373 during the test. Participants did not report any difficulties with the placement of the sensors.

374 This study is not without limitations. Indeed, the sample size is limited to generalize the results. The
 375 model parameters need to be modified and adapted if the procedure changes. The calculation of the
 376 discrete levels is dependent on the size and performance of the groups in order to translate the
 377 measurements recorded by the motion sensors into their equivalent grades.

378 While an effort to keep the conditions of the test as standard as possible was made, the use of wet
 379 models implies a deterioration of the model with each procedure performed. The use of a standard
 380 model (synthetic model for example) validated for each participant could help reduce the variance that
 381 might be introduced by the manipulation of the animal model.

382

383 5. Conclusion

384 The use of recording sensors to objectively assess performance parameters should eventually make it
 385 possible to certify the skills of future practitioners.

386 In dentistry, as in other medical fields, it is necessary to identify the relevant criteria and then find a
 387 simple way to measure these criteria. Here we have studied the value and usability of a motion sensor
 388 system, allowing us to assess the economy of movement and flow of operation criteria. However,
 389 other criteria and sensors should be considered in order to achieve a completely objective evaluation.
 390 The establishment of such a system could enable self-assessment that would be relevant for students.

391 By combining these results with an image analysis, such as that proposed by Frischknecht
 392 (Frischknecht et al., 2013), a complete objective assessment of basic skills in oral surgery could be
 393 considered.

394 6. Acknowledgment

395 The authors would like to thank all the students and surgeons that participated in the study. In
 396 particular, the authors are grateful to the engineering students that helped run the experiments: Jessy
 397 Vincente, Maud Turin, Noel Vignacq, Adrian Carpinteiro, and Paola Romo. We would also like to
 398 thanks Fabio Cruz for its help debugging our data analysis scripts.

399 7. Appendix A. Participants' assessment notes for expert only and mixed methods

400 Table A.7. Participants' assessment with expert only and mixed method.

| CODE | Category | Respect of tissues | Time and motion | Tool use | Fluidity | Procedural knowledge | Total grade (expert only) | Fluidity grade (proposed) | Economy grade (proposed) | Total grade (mixed) |
|------|--------------|--------------------|-----------------|----------|----------|----------------------|---------------------------|---------------------------|--------------------------|---------------------|
| 1 | experienced | 5 | 5 | 4 | 4 | 5 | 23 | 5 | 5 | 24 |
| 10 | experienced | 4 | 5 | 5 | 5 | 4 | 23 | 4 | 5 | 22 |
| 2 | experienced | 5 | 4 | 4 | 4 | 5 | 22 | 5 | 5 | 24 |
| 26 | experienced | 4 | 4 | 5 | 5 | 4 | 22 | 4 | 5 | 22 |
| 7 | novice | 4 | 5 | 4 | 5 | 4 | 22 | 4 | 5 | 21 |
| 3 | intermediate | 4 | 4 | 4 | 4 | 5 | 21 | 4 | 4 | 21 |

| | | | | | | | | | | |
|----|--------------|---|---|---|---|---|----|---|---|----|
| 5 | experienced | 4 | 4 | 4 | 4 | 4 | 20 | 5 | 5 | 22 |
| 6 | experienced | 4 | 4 | 4 | 4 | 4 | 20 | 4 | 5 | 21 |
| 9 | intermediate | 4 | 4 | 4 | 4 | 4 | 20 | 3 | 1 | 16 |
| 4 | intermediate | 4 | 4 | 4 | 4 | 4 | 20 | 4 | 5 | 21 |
| 18 | intermediate | 4 | 4 | 3 | 4 | 4 | 19 | 3 | 5 | 19 |
| 8 | intermediate | 4 | 3 | 4 | 4 | 3 | 18 | 4 | 5 | 20 |
| 11 | intermediate | 4 | 4 | 3 | 3 | 4 | 18 | 4 | 5 | 20 |
| 12 | intermediate | 4 | 3 | 4 | 3 | 3 | 17 | 4 | 5 | 20 |
| 13 | intermediate | 4 | 3 | 3 | 3 | 4 | 17 | 4 | 5 | 20 |
| 14 | intermediate | 4 | 3 | 3 | 3 | 4 | 17 | 3 | 4 | 18 |
| 28 | intermediate | 4 | 3 | 3 | 3 | 4 | 17 | 5 | 5 | 21 |
| 29 | intermediate | 4 | 4 | 3 | 4 | 2 | 17 | 5 | 5 | 19 |
| 15 | intermediate | 4 | 3 | 3 | 3 | 3 | 16 | 3 | 5 | 18 |
| 27 | novice | 3 | 4 | 3 | 3 | 3 | 16 | 3 | 5 | 17 |
| 20 | novice | 3 | 3 | 2 | 3 | 3 | 14 | 4 | 5 | 17 |
| 19 | novice | 3 | 3 | 2 | 3 | 3 | 14 | 3 | 5 | 16 |
| 16 | intermediate | 3 | 2 | 3 | 3 | 2 | 13 | 3 | 4 | 15 |
| 17 | intermediate | 3 | 2 | 1 | 2 | 4 | 12 | 3 | 5 | 16 |
| 21 | novice | 3 | 1 | 2 | 2 | 3 | 11 | 1 | 1 | 10 |
| 22 | novice | 2 | 2 | 2 | 3 | 1 | 10 | 3 | 1 | 9 |
| 25 | experienced | 2 | 1 | 2 | 2 | 3 | 10 | 4 | 5 | 16 |
| 23 | novice | 1 | 2 | 2 | 2 | 2 | 9 | 1 | 4 | 10 |
| 24 | novice | 1 | 1 | 1 | 1 | 1 | 5 | 1 | 4 | 8 |

401

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