Simulator assessment of innate endovascular aptitude versus empirically correct performance

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Objective: **Prior work has established that performance on an endovascular simulator incorporating tactile feedback (haptics) correlates with previous endovascular experience and can be improved by training. This study was designed to test the ability to define and measure innate endovascular aptitude and empirically correct performance and to determine whether these are two different things.**

Methods: **Subjects ranging in endovascular skill level from novice to expert were surveyed to determine video game experience and skill, endovascular level of training, and endovascular experience. They were then tested by using a standard protocol requiring timed advancement of a catheter and wire sequentially into each of three vessels arising from a simulated type I arch. Recorded trials were independently and blindly scored by two experienced endovascular faculty members by using a modification of a previously validated scale (Modified Reznick Scale; MRS). Summed scores were analyzed by frequency analysis and categorized as satisfactory and unsatisfactory on the basis of a clear bimodal distribution. Categorical outcome, time to task completion, and other variables were analyzed by means of linear regression, analysis of variance, and Welch modified two-sample *t* tests, as indicated.**

Results: **A total of 61 subjects were enrolled: 42% students, 8% technicians, 19% surgeons, 13% cardiologists, and 18% radiologists. Of these, 62% were considered novices and 30% experts on the basis of previous experience; 56% of subjects worked in an endovascular-related occupation. MRS scores were highly correlated between raters ($P < .0001$) and showed a clear bimodal distribution, with subjects in any endovascular occupation (including technicians) scoring significantly better than all others ($P < .0001$). Hours of video games played per week were correlated highly with completion times ($P < .001$) and MRS scores ($P < .001$). Measures of formal training (number of endovascular cases and occupation) correlated highly with completion times (all $P < .03$) and MRS scores (all $P < .008$). In comparing completion times vs MRS scores, three groups were apparent: unskilled-inexperienced, skilled-inexperienced, and skilled-experienced, corresponding primarily to senior subjects without endovascular experience, younger subjects without endovascular experience, and formally trained endovascular physicians, respectively. Those judged intermediate in aptitude reduced times to the lowest possible level before improving their MRS scores.**

Conclusions: **Although inherently subjective, the MRS yields reproducible scores that correlate with endovascular experience and formal training. Experts and novices with extensive video game experience achieve short completion times, whereas high MRS scores are achieved only by formally trained subjects. Innate endovascular aptitude and empirically correct performance may be two separate things, and aptitude may be acquirable through (or identified by) extensive nonmedical video game experience. (J Vasc Surg 2006;43:47-55.)**

Endovascular therapy has become an integral part of modern vascular surgery. New training paradigms have been created, and with the increasing use of medical simulators, interest has arisen in using simulator technology to teach endovascular surgery. Simulators can be used in three ways: first, to identify and quantify existent skill at any point in time; second, to teach and train individuals in endovascular skills; and third, to practice a specific procedure before it is performed on a patient.

Our interest has so far been focused on the first two items. Recent work has shown that an endovascular simulator that uses tactile feedback (haptics) is valid and that, in some ways, it successfully mimics an actual clinical scenario. Initial performance is correlated with prior experience, and repetition leads to improved performance.[1,2] We are not satisfied, however, that we know what "performance" really is or how to measure it. We therefore hypothesized that "innate endovascular aptitude" and "empirically correct performance" are two different things, are measured in different ways, and correlate with different aspects of the subject's background. This study was designed to explore these questions, to begin development of an endovascular rating scale, and to correlate time and rating scale results with subjects' past experiences.

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METHODS

Endovascular simulator. The Vascular Intervention System Training simulator (Mentice AB, Gothenburg, Sweden) consists of a haptics interface unit coupled to a desktop computer running the Procedicus (Mentice AB) simulation software. Real endovascular instruments can be introduced into the haptic interface unit and, by using simulated fluoroscopy, displayed within the vascular anatomy on a computer monitor (Fig 1). On-screen instrument

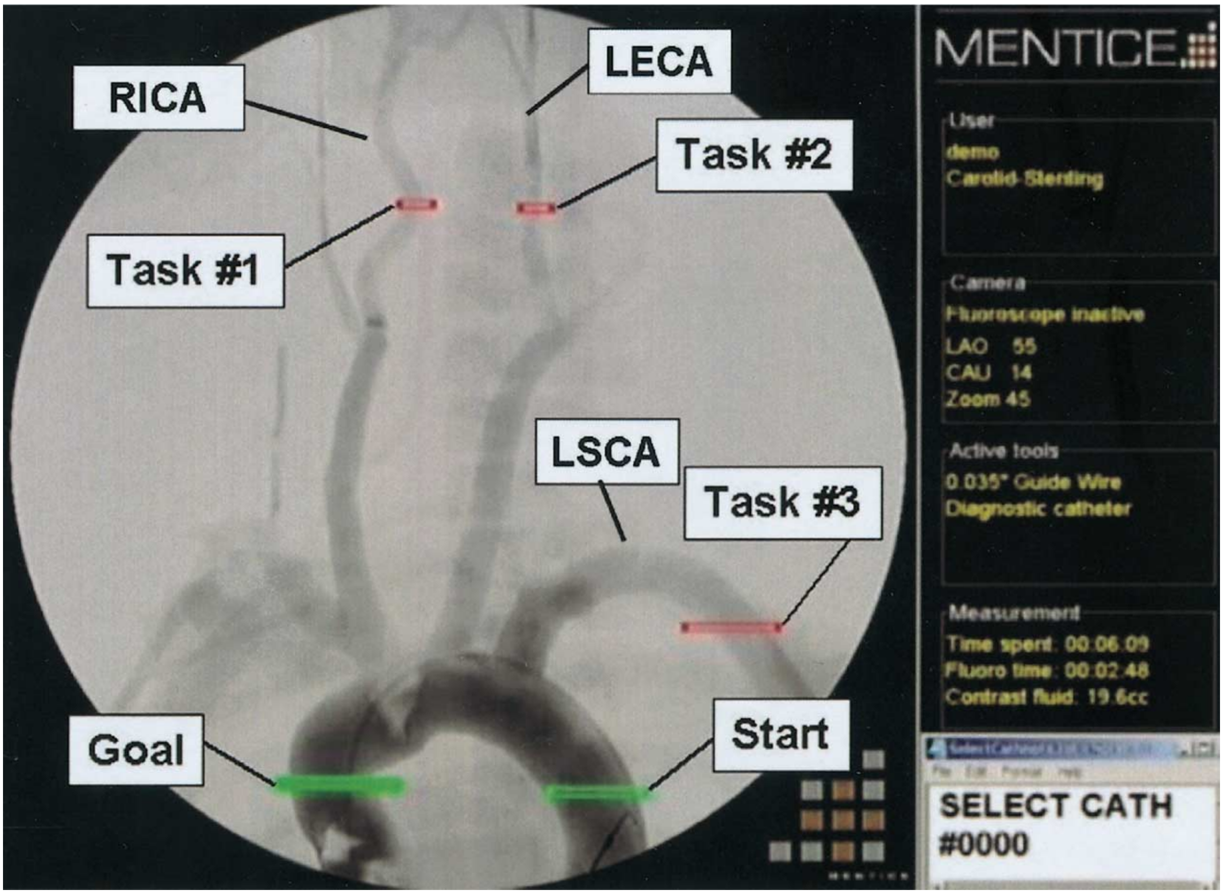

Fig 1. Simulated anatomy with task and vessel labels. *RICA,* Right internal carotid artery; *LECA,* left external carotid artery (more visible than the internal carotid artery in this model); *LSCA,* left subclavian artery. *Start* is the line at which the catheter is initially positioned; *goal* is the line used to pass the catheter to during the initial 2-minute orientation/break-in period (see text).

Table I. Proctor guidelines

Actions permitted
Operate a stopwatch
Operate recording equipment
Identify instruments
Acknowledge task completion
Pre-empt and recover from simulator malfunction
Terminate session upon trial completion
Actions not permitted
Handle tools while inserted
Suggest actions that aid in progress
Provide feedback during the procedure

characteristics, such as size, shape, deployment, and retrieval, are simulated. Fluoroscopy is activated by foot pedal controls, and a syringe is used for simulated contrast injection. An additional touch-screen monitor allows for selecting desired instruments and using the simulator's cine-loop and road-mapping capabilities. Joystick controls allow for table and fluoroscopic C-arm positioning.

Three-vessel selective catheterization model. Formal ("low risk") institutional review board approval was obtained for this study. After consent, subjects completed an entrance survey to collect pertinent demographic, opinion, and previous endovascular experience data. After completion, participants were shown a brief PowerPoint (Microsoft Corp, Redmond, Wash) presentation outlining the objectives of the session, including a recorded demonstration of selective catheterization of a single vessel on the Vascular Intervention System Training simulator performed on an anatomical structure different from that of the study protocol. After orientation, each participant completed a break-in session that consisted of a 2-minute period during which guidewires and catheters were advanced within the aortic arch from the distal starting line in the descending aorta to the proximal goal line in the ascending aorta and back as many times as possible (Fig 1). The purpose of the break-in session was to familiarize the subject with the simulator and to prevent potentially damaging behavior to the simulator.

Modified Reznick Scale

	1	2	3	4	5
1. Respect for Tissue	Frequently used unnecessary force on tissue and/or lesion, potential for tissue damage		Careful handling of tissue and/or lesion, but occasional potential for inadvertent tissue damage		Consistently handled tissue and/or lesion appropriately with minimal damage to tissue
2. Time and Motion	Many unnecessary moves and/or excessive time		Efficient time and moves, but some unnecessary moves and/or excessive time		Clear economy of moves and time with maximum efficiency
3. Instrument Handling	Repeated tentative, awkward, and/or inappropriate moves with instruments		Competent use of instruments, but occasionally appeared stiff or awkward		Fluid movements with instruments and no stiffness or awkwardness
4. Flow of Operation	Frequently stopped operating and seemed unsure of next move; demonstrated imprecise and/or wrong operative technique		Demonstrated some forward planning with reasonable progression of procedure; careful operative technique with occasional errors		Planned course of operation with effortless flow throughout; fluent, secure, and correct operative technique in all stages of procedure
OVERALL PERFORMANCE	1 Very poor	2	3 Competent	4	5 Clearly superior
FINAL PRODUCT	1 Unacceptable quality	2	3 Average quality	4	5 Superior quality
SCORE	Items 1-4			Total	
PASS RATING	Would you feel confident in allowing this trainee to perform this procedure, under supervision, in the				YES • NO

Fig 2. Modified Reznick Scale used for scoring by evaluators. See text for description.

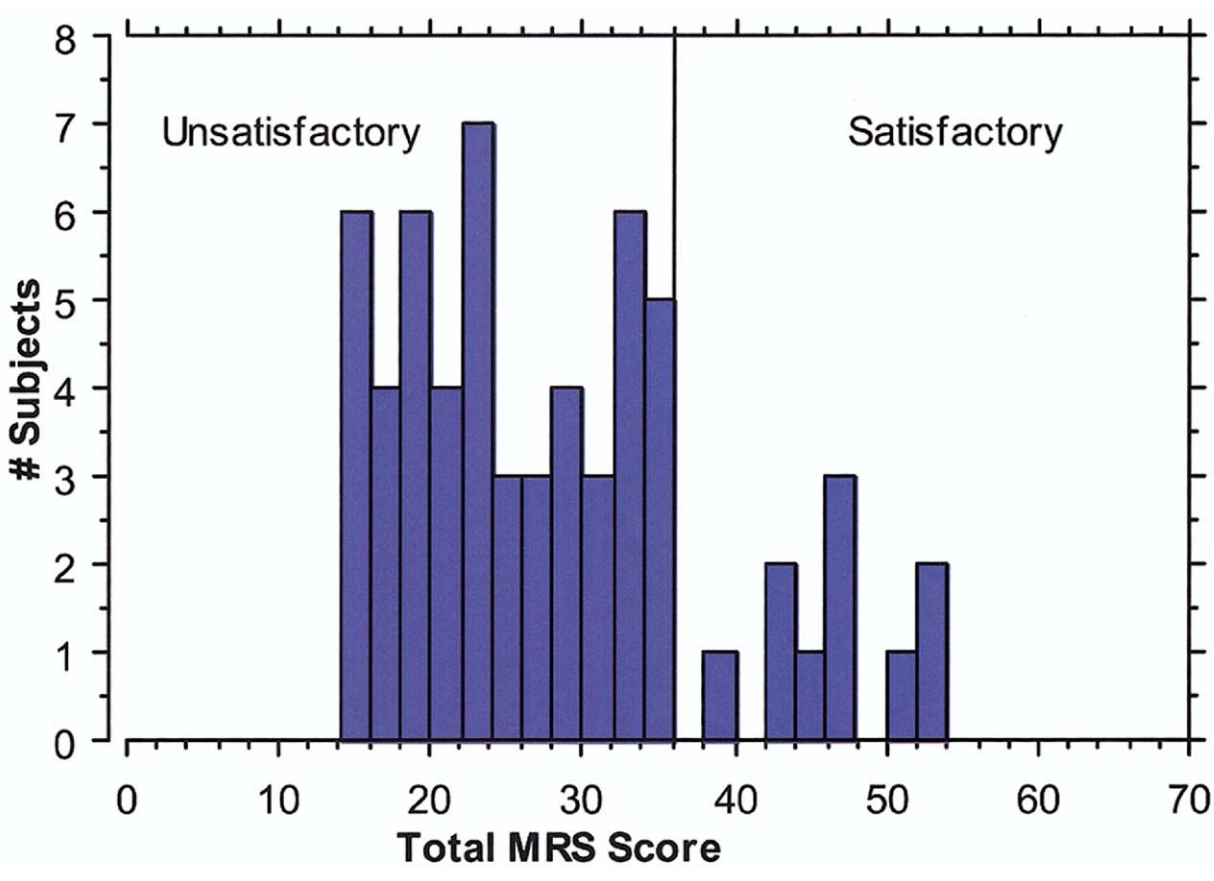

Fig 3. Histogram of Modified Reznick Scale *(MRS)* score vs number of subjects.

Table II. Subject demographics versus skill level

	Experience level (N = 61)		
Variable	*Novice (n = 39)*	*Intermediate (n = 4)*	*Expert (n = 18)*
Age, y, mean (mean ± SD)	30.6 ± 11.7	34 ± 8.2	39.9 ± 6.7
No. endovascular cases in past 2 y (mean ± SD)	1.2 ± 5.8	51 ± 16.4	999.7 ± 968.4
Level of training			
Technician	4	0	0
Medical student	25	0	0
Resident	1	2	0
Fellow	2	1	4
Nonendovascular faculty	4	0	1
Endovascular faculty	0	1	13
Other	3	0	0
Field of specialization			
Technician	4	0	0
Student	25	0	0
Surgery	5	2	5
Cardiology	2	0	6
Radiology	0	2	7
Other	3	0	0
Endovascular-related field			
Yes	6	3	17
No	33	1	1

The experience level was defined by the total number of endovascular cases in the past 2 years: novice (0-19), intermediate (20-99), or expert (≥100). Subjects were considered as being in an endovascular-related field if they were fellows or faculty members in interventional cardiology, interventional radiology, or vascular surgery or were interventional radiology technicians.

Table III. Video game skill

	Video game skill level (N = 61)		
Variable	*None (n = 21)*	*Moderate (n = 35)*	*Advanced (n = 5)*
Age, y, mean (mean ± SD)	34.9 ± 15.2	33.11 ± 8.3	31.2 ± 6.7
No. endovascular cases inpast 2 y (mean ± SD)	163 ± 476.4	417.8 ± 817.1	40.2 ± 89.3
Level of training			
Technician	3	1	0
Medical student	10	13	2
Resident	1	1	1
Fellow	3	4	0
Nonendovascular faculty	2	3	0
Endovascular faculty	2	11	1
Other	0	2	1

Video game skill level was self-reported on a scale of 1 to 5. None was defined as a rating of 1, advanced as a rating of 5, and moderate as a rating of 2, 3, or 4.

The study protocol followed the break-in session. Two blinded video recordings were made of each subject during completion of the study protocol. The first was an internally captured recording of the simulator's fluoroscopy screen recorded with GigaPocket version 5.5 (Sony Corp, New York, NY). The second was an external video recording (without audio) made of the subject's hands manipulating the instruments adjacent to the haptics unit. Each subject wore a surgical gown and gloves to conceal identifying characteristics. Only the subject's study identification number was captured in these recordings.

A standardized road-mapped type I aortic arch with three nonoccluded great vessels oriented at 55° left anterior oblique and 14° caudal angles was used as an anatomic template (Fig 1). The start line, goal line, and task lines were labeled digitally on the fluoroscopy screen by using Linktivity Presenter version 1.0 (Linktivity, Tucson, Ariz). The goal line was not used in the experimental protocol. Each subject began the session with a Simmons/Sidewinder 2 diagnostic catheter and 0.035-inch J-tip guidewire introduced into the simulator and located at the start line in the descending aorta. Subjects were given the task of selectively catheterizing the following three vessels, in this order: right internal carotid artery, left external carotid artery, and left subclavian artery. For a vessel to be considered selectively catheterized, both the guidewire and the diagnostic catheter had to be simultaneously advanced beyond the task line in each vessel (Fig 1).

A proctor (one of the study investigators) was present during each trial to properly set up the simulator and to record images and times. Rules governing their actions are listed in Table I and were posted for subject reference. After completion, participants were instructed not to discuss the protocol with anyone other than study investigators.

Data acquisition and analysis. Two general sets of outcome measures were recorded: time to completion of each task and subjective assessment of skill. Times to completion of each task and the overall study session were externally timed by the proctor by using a stopwatch. Subjective assessment of skill was made independently by two experienced endovascular physicians (K.A.I. and C.N.) by using a modification of a previously validated skills assessment scale. The original scale, described by Reznick,[3] consisted of seven categories that together were used to rate operative performance. We modified this by dropping three unneeded categories, thus leaving "respect for tissue," "time and motion," "instrument handling," and "flow of operation" only, and by adding a judgment of overall performance and final product (the end result, irrespective of the methods needed to get there). Each variable is rated from 1 to 5 on a Likert scale with a descriptor in the middle and at either end. Finally, a subjective judgment as to whether the rater would be comfortable taking the subject through this procedure in the operating room under supervision was added; the resulting simplified rating scale was referred to as the Modified Reznick Scale (MRS; Fig 2).

Definitions. Subjects' skill levels were classified as "expert" if they had personally performed 100 or more

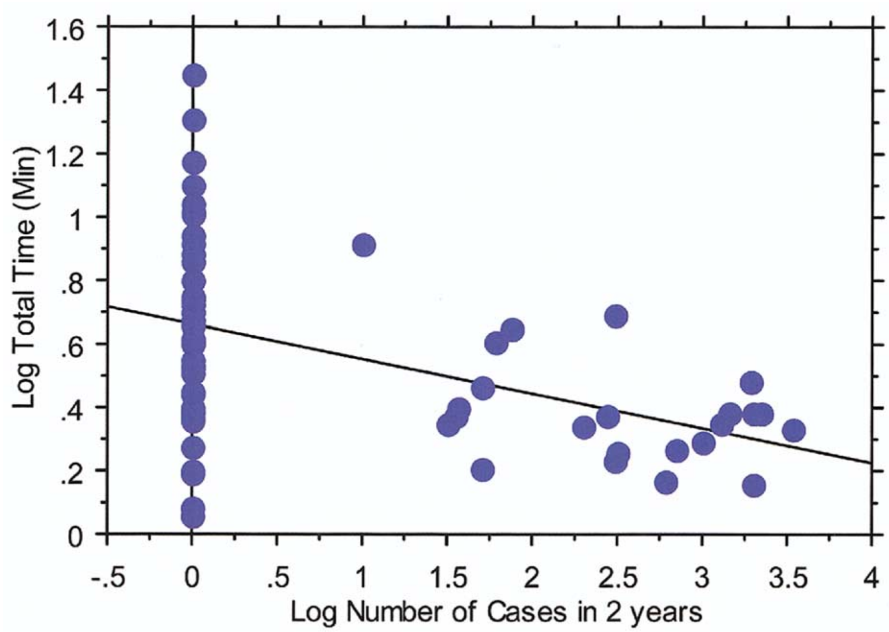

Fig 4. Scattergram of log number of endovascular cases in the past 2 years vs log total time (min) with regression line (P = .027).

endovascular cases in the past 2 years, "novice" if they had performed fewer than 20, and "intermediate" if their experience lay between these two points. Subjects were also classified by their level of training, field of specialization, and whether they practiced as endovascular physicians. Finally, self-reported video game skill was recorded on a scale of 1 (novice) to 5 (advanced).

Statistical analysis. Completion times and MRS scores were correlated with skill, level of training, field of specialization, scope of practice, and video game experience. MRS scores were recorded numerically for regression analysis; scores were divided into "satisfactory" (summed total MRS score >36) or "unsatisfactory" (summed score ≤36) categories for analysis after frequency analysis demonstrated a clear bimodal distribution (Fig 3). Linear regression, Welch modified two-sample *t* tests, and analysis of variance with post hoc testing (multiple groups), as indicated, were used for analysis with S-Plus (Insightful Corp). Unless otherwise specified, all numeric results are expressed as means ± SD; minutes are expressed in decimal fashion.

RESULTS

Participants. A total of 64 participants were initially recruited for the study; 61 completed the study and were used for analysis. The final group consisted of 38 (62%) novices, 18 (30%) experts, and 5 (8%) intermediates. Most subjects, all novices, were medical students, whereas endovascular-trained faculty (vascular surgeons, interventional radiologists, and cardiologists) made up the next most common group. Experts almost exclusively (95%) practiced in endovascular-related fields, whereas intermediates tended to be residents and fellows (Table II). Twenty-one subjects described themselves as having no video game skill at all, and five subjects described themselves as advanced video game players (Table III).

Time to task completion. Times to completion of each task and to completion of the total exercise were highly correlated among endovascular novices with hours of video games played per week ($P < .001$) and among all participants with measures of endovascular skill and exposure (occupation and number of endovascular cases performed; both $P < .001$). There was no correlation with the current amount of computer use ($P = .96$). Although only three interventional radiology technicians were tested, they did quite well and achieved overall times similar to those of endovascular faculty (2.8 ± 2.0 minutes vs 2.2 ± 0.47 minutes, respectively; $P = .84$). When time to completion is plotted against the (log) number of endovascular cases performed, it is apparent that virtually any endovascular experience results in an immediate decrease in time to almost minimal levels (Fig 4).

MRS numerical scores. Numerical scores were highly correlated between the two raters ($P < .0001$) and with the number of endovascular cases performed ($P = .008$). Frequency analysis showed a bimodal distribution, with a cutoff at 36 (Fig 3). The 10 subjects who made up the "satisfactory" group were all endovascular faculty (interestingly, however, four endovascular faculty members were rated as "unsatisfactory" by this analysis). All IR technicians and fellows, including cardiology, interventional radiology, and vascular surgery (this study was performed in the fall), were rated "unsatisfactory" (Tables IV and V). Level of training and occupation both correlated highly with MRS scores ($P < .0001$). Number of video game hours played

Table IV. Subject demographics versus performance

Variable	Performance (N = 61) Satisfactory (n = 10)	Unsatisfactory (n = 51)
Age, y, mean (mean ± SD)	43.5 ± 6.4	31.6 ± 10.7
No. endovascular cases in past 2 y (mean ± SD)	1096 ± 844.4	142.7 ± 537.9
Level of training		
Technician	0	4
Medical student	0	25
Resident	0	3
Fellow	0	7
Nonendovascular faculty	0	5
Endovascular faculty	10	4
Other	0	3
Field of specialization		
Technician	0	4
Student	0	26
Surgery	4	8
Cardiology	2	6
Radiology	4	5
Other	0	2
Endovascular related field		
Yes	10	16
No	0	35

"Satisfactory" and "unsatisfactory" were based on Modified Reznick Scale scores of greater than or less than 35, respectively (see text). Subjects were considered as being in an endovascular-related field if they were fellows or faculty members in interventional cardiology, interventional radiology, or vascular surgery or were interventional radiology technicians.

Table V. Endovascular skill level versus performance

Endovascular experience level	*Satisfactory (n = 10)*	*Unsatisfactory (n = 51)*
Novice (n = 39)	0	39
Intermediate (n = 4)	1	3
Expert (n = 18)	9	9

Endovascular experience level was assessed by the number of cases and satisfactory or unsatisfactory Modified Reznick Scale scores; see text and Tables II and IV for definitions and cutoff values.

per week among endovascular novices also correlated highly with MRS scores ($P < .001$). MRS scores increased with increasing endovascular experience (Fig 5).

Comparison of time and MRS scores. The most interesting result was obtained when the total time to completion of the task and summed MRS numeric scores from both evaluators were plotted on a scattergram (Fig 6); it should be stressed that MRS scores are qualitative data. Four groups are apparent, with (arbitrary) cutoffs of 5 minutes' total time and a total MRS score of 25 based on the longest time for completion and the lowest total MRS score for any subject that was passed by at least one evaluator. Subjects in the very bottom right quadrant (high scores and low times), labeled skilled-trained, correspond to practicing endovascular surgeons. Subjects in the very bottom left quadrant (low scores but fast times), labeled skilled-untrained, correspond to young subjects, mostly medical students, with extensive video game experience but no formal endovascular training. Finally, subjects in the top left quadrant (low scores and high times), labeled unskilled-untrained, correspond to senior surgeons without video game experience and without endovascular training (Table VI). No subjects fell into the hypothetical unskilled-trained quadrant.

Fifteen subjects were passed by both examiners (Fig 6; *blue*), and 34 were failed *(red)* by both; in 12 cases there was disagreement *(green)*. Endovascular faculty in general, but specifically those with a large number of recent cases, were most likely to be passed by both examiners ($P <$ .0001). Passing correlated highly with endovascular experience and level of training (both $P < .0001$), but not with video game hours played per week or current computer hours. The "equivocal" group consisted of four fellows (three cardiology and one interventional radiology), two endovascular faculty members (cardiology and radiology), one nonendovascular faculty member (surgery), two medical students, two interventional radiology technicians, and one radiology resident.

DISCUSSION

Our results suggest that innate endovascular aptitude, measured by the time to complete a set task without instructions as to technique, and empirically correct performance, subjectively evaluated with the MRS by experienced endovascular faculty, may be two different things. Time to complete the task is improved by hours of video games played per week and amount of formal training, whereas MRS scores are improved to the point of being deemed of satisfactory performance only by formal endovascular training. Subjects with neither video game skill nor formal training take a long time to complete the task and appear awkward.

The finding that untrained subjects with extensive video game experience complete the task quickly is interesting but not unexpected. One major difference between conventional surgery and endovascular procedures is that during conventional surgery, the operator is looking directly at the procedure being performed in a three-dimensional environment, whereas during endovascular procedures, the operator is looking somewhere other than his or her hands (ie, the monitor). In addition, the endovascular physician is translating two-dimensional hand movements (insertion/withdrawal and rotation only) at the access point into movement of objects (ie, catheters, wires, and other tools) in a three-dimensional endovascular environment at a distance. It may be that extensive video game experience, although much different in detail as compared with clinical endovascular techniques, is beneficial in terms of raw time by training the subject to work effectively under these conditions. In other words, looking at objects on a screen being affected by unwatched hand movements at a distance, regardless of visual or intellectual content, is beneficial in relation to raw time. These subjects had an innate ability to manipulate objects on a screen by

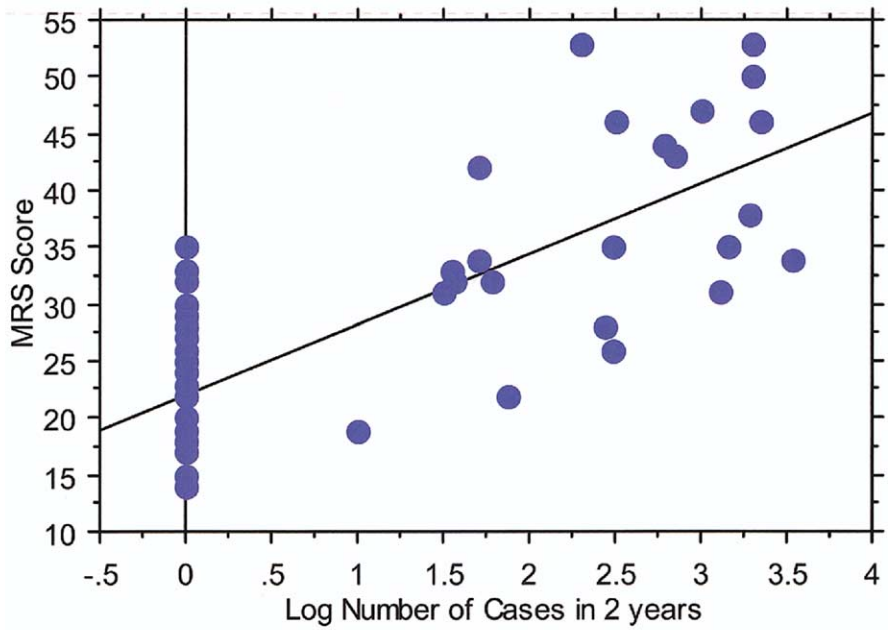

Fig 5. Scattergram of log number of endovascular cases in the past 2 years vs Modified Reznick Scale *(MRS)* score with regression line ($P = .008$).

using their hands and were able to quickly translate errors into effective movements (although, in their untrained state, in ways that would be quite dangerous in living humans). It has been shown that video game playing enhances visual attention capacity and spatial distribution and allows individuals to avoid bottlenecks of attention.[4]

By contrast to raw completion times, MRS scores were high only in participants with formal endovascular training. This finding also was not unexpected, because the scale emphasizes things we are all trained to do: handle instruments properly, use correct technique, and treat tissues carefully. The measuring tool and desired outcome are inextricably confounded with each other at this point. We have been careful, for this reason, to use the term "empirically correct performance" for that set of skills, presumably taught during formal training, that we believe leads to the best outcome.

The finding that subjects who were passed by one rater and failed by the other had low (good) times but only fair MRS scores is interesting. If one accepts the premise that these are subjects intermediate in skill, and thus trainees (four fellows, one radiology resident, and two medical students, in addition to two endovascular faculty members, one nonendovascular surgeon, and two interventional radiology technicians), then these data suggest that the first thing that occurs at the beginning of formal training is a decrease in overall time, which then is followed only later by improvement in technique. Longitudinal evaluation of individuals will be required to prove this.

There are two ways to achieve a fast time in our model (gain extensive experience with video games or go through formal endovascular training) but only one way to be judged to have performed well (undergo formal training). The third group, participants without either video experience or formal endovascular training, uniformly took a long time to complete the task and appeared awkward doing so. These were mostly senior surgeons, highly skilled in their fields, but without the specific type of hand-eye coordination video gaming teaches. This indicates that hand-eye coordination gained by performing surgery and hand-eye coordination gained by video game and/or endovascular experience may be unrelated.

Direct observation of technical skill is inherently subjective. The Objective Structured Assessment of Technical Skills is a protocol that attempts to create as much objectivity as possible by using a validated Global Rating Scale of Operative Performance (GRSOP) that evaluates seven components of surgical skill.[5] Preliminary investigation has demonstrated this type of scale to be more reliable and accurate compared with task-specific checklists in the assessment of surgical procedures.[6] The main drawback to Objective Structured Assessment of Technical Skills assessment is the resource commitment required (surgeons) to accurately evaluate subjects at the time of examination. In addition, bias is introduced by evaluators being physically present and therefore not blinded. We modified Reznick's GRSOP scale for this study, shortening it but not adding any factors specific to endovascular procedures. The GRSOP has previously been similarly modified for evaluation of performance of simulated endourologic,[7,8] orthopedic,[9] plastic,[10] and actual laparoscopic[11] surgery.

As with many other studies, our data suggest more questions than answers. One such question is whether a

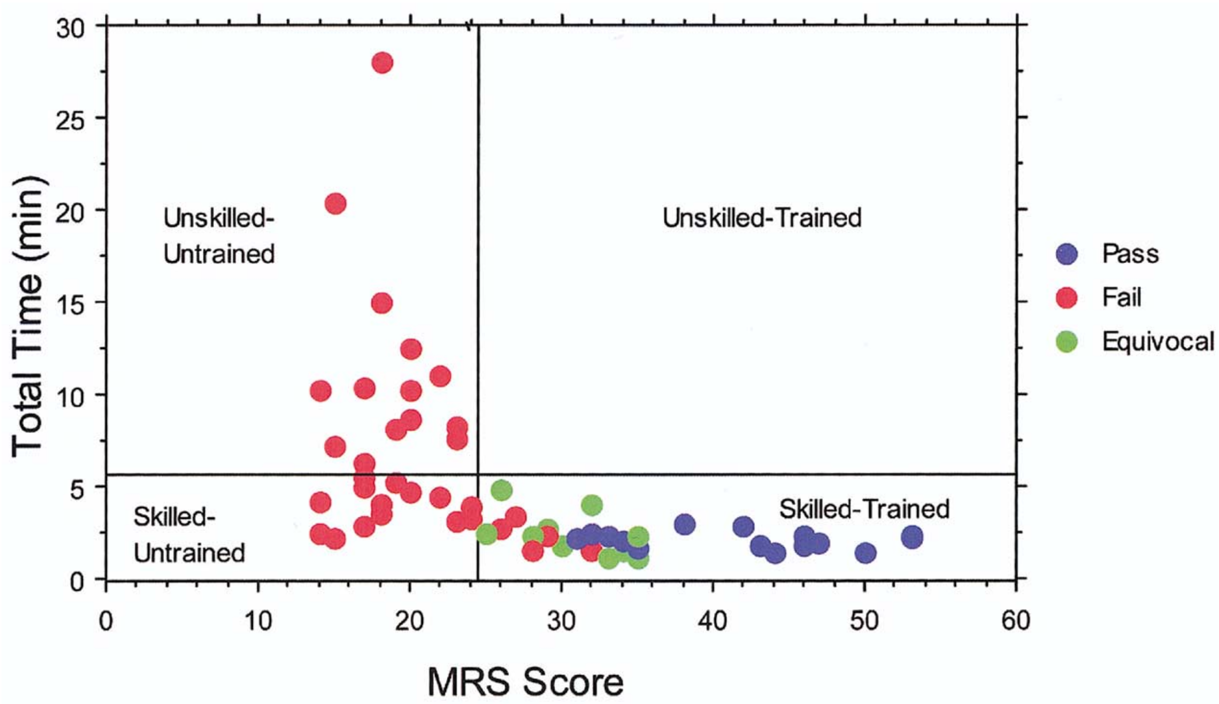

Fig 6. Scattergram of Modified Reznick Scale *(MRS)* score vs total time (minutes) split by pass/fail status. *Pass,* Passed by both evaluators; *Fail,* failed by both evaluators; *Equivocal,* passed by one evaluator, but not the other.

Table VI. Skill versus training

Variable	*Skilled-trained (n = 32)*	*Skilled-untrained (n = 11)*	*Unskilled-untrained (n = 18)*
Age, y, mean (mean ± SD)	36.2 ± 8.1	29.88 ± 7.5	31.2 ± 15.7
No. endovascular cases in past 2 y (mean ± SD)	567.6 ± 873.1	6.6 ± 21.7	0.6 ± 2.4
Time to completion, min (mean ± SD)	2.30 ± 0.79	3.70 ± 0.81	10.32 ± 5.88
Average subject			
Video skill level	Moderate	Moderate	None
Level of training	Endovascular faculty	Medical student	Medical student/ senior surgeon
Field of specialty	Radiology	Medical Student	Medical student/ senior surgeon
Endovascular-related field	Yes	No	No

See text and Fig 5 for definitions.

fast time at an untrained point (our prototypical skilled-untrained medical student) predicts later success after training. In other words, do physicians with faster times make better endovascular (or laparoscopic) surgeons? Another question yet to be answered is how to truly assess best performance. The MRS, as described previously, is inextricably confounded with what we believe to be good technique. A more valuable evaluative protocol would contain actual clinical outcome as a determinant of performance. Also, how does each of these variables (time and MRS scoring) change with time and training, and can they predict what different training techniques should be used for different people with different backgrounds? Finally, our MRS is subjective, somewhat redundant, and unvalidated (partially because we do not know what "performance" and "aptitude" really are) and will therefore need to be better explored.

In conclusion, we believe that the ability to complete a set task on an endovascular simulator in a short period of time (innate endovascular aptitude) can be gained by either extensive video game experience or formal endovascular training, whereas subjective expert assessment of proper technique (empirically correct performance) is achievable by formal endovascular training only. This raises the possibility that video game (or equivalent) experience is beneficial to a future career in endovascular surgery, but proof of this (as well as the predictive value of this finding and differences within this group) awaits further research.

AUTHOR CONTRIBUTIONS

Conception and design: SJH, JHH, BTG RJ, DS, KAI
Data collection: SJH, BTG, CN, RJ, DS, KAI
Analysis and interpretation: SJH, KAI, JHH, AA
Writing the article: SJH, KAI, AA, BTG, RJ, DS, JHH
Critical revision of the article: SJH, KAI, AA, BTG, RJ, DS, JHH
Final approval of the article: SJH, KAI, AA, BTG, RJ, DS, JHH
Statistical analysis: AA
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Overall responsibility: SJH

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