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Virtual patient simulations and optimal social learning context: A replication of an aptitude–treatment interaction effect

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Abstract

Background—Virtual patients (VPs) offer valuable alternative encounters when live patients with rare conditions, such as cranial nerve (CN) palsies, are unavailable; however, little is known regarding simulation and optimal social learning context.

Aim—Compare learning outcomes and perspectives between students interacting with VPs in individual and team contexts.

Methods—Seventy-eight medical students were randomly assigned to interview and examine four VPs with possible CN damage either as individuals or in three-person teams, using *Neurological Examination Rehearsal Virtual Environment* (NERVE). Learning was measured through diagnosis accuracy and pre-/post-simulation knowledge scores. Perspectives of learning context were collected post-simulation.

Results—Students in teams submitted correct diagnoses significantly more often than students as individuals for CN-IV ($p = 0.04$; team = 86.1%; individual = 65.9%) and CN-VI ($p = 0.03$; team = 97.2%; individual = 80.5%). Knowledge scores increased significantly in both contexts

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(p<50.001); however, a significant aptitude–treatment interaction effect was observed ($p = 0.04$). At pre-test scores ≤25.8%, students in teams scored significantly higher (66.7%) than students as individuals (43.1%) at post-test ($p = 0.03$). Students recommended implementing future NERVE exercises in teams over five other modality-timing combinations.

Conclusion—Results allow us to define best practices for integrating VP simulators into medical education. Implementing NERVE experiences in team environments with medical students in the future may be preferable.

Introduction

Medical educators face numerous challenges when embedding clinical exposure opportunities for students in the undergraduate curriculum, especially when live patients with specific clinical conditions of interest are unavailable. In these cases, the Liaison Committee on Medical Education (LCME) states that “the medical student should be able to remedy the gap by a simulated experience” (LCME 2011, Standard ED-2, p. 7). Virtual patients (VPs) presented through computer-based systems offer valuable educational encounters due to their capacity to mimic a variety of complex pathologies and clinical scenarios (Huang et al. 2007; Ellaway et al. 2009). Computer-based VP simulations are affordable, widely distributable and can be made accessible on demand (Danforth et al. 2009), allowing for student engagement independent of, or supplemental to, classroom and clerkship experiences.

A gap that exists in undergraduate medical education is student exposure to patients with cranial nerve (CN) palsies. While these abnormalities are relatively rare, it is critical for students to learn to recognize and diagnose neurologic disease (Gelb et al. 2002). Limited opportunities for practice have been associated with student reports of poor knowledge and confidence regarding performance of the neurologic exam (Schon et al. 2002; Moore & Chalk 2009).

To address this gap, a computer-based simulation system entitled, *Neurological Examination Rehearsal Virtual Environment* (NERVE), was created to allow students to engage VPs in unscripted conversations for history-taking and conduct physical examinations of VPs using virtual tools (e.g. ophthalmoscope, physician hand and eye chart; Figure 1). User-typed questions and instructions are responded to verbally or behaviorally by NERVE VPs; for example, VPs can answer the question, “Have you experienced any trauma to your head?” and can follow the directive, “Read this line” (Figure 2). VPs currently recognize and respond to over 1200 questions. Embedded clinical scenarios allow students to synthesize patient history details and examination findings to formulate diagnoses.

Effectively integrating simulation experiences into the curriculum presents its own set of challenges (e.g. availability of expert faculty members, educational space, equipment and allowable student contact hours). Accordingly, understanding best practices associated with the use of novel simulation technologies is essential. Student outcomes following interactions with NERVE VPs were previously compared between individual and small-group learning contexts (Johnson et al. 2013), as collaborative learning processes are suggested to promote critical thinking and enhance engagement in training (Gokhale 1995; Kraiger 2008). Examining pre- and post-test CN-specific knowledge scores among 57 second-year medical students by social learning context, researchers observed an aptitude–treatment interaction (ATI) effect related to learning. At pre-test scores ≤50%, students who used NERVE as members of three-person teams scored significantly higher (83%) at post-test than did students who used NERVE as individuals (62%). In addition, following NERVE use, students who performed in teams reported significantly greater confidence in their abilities to diagnose CN palsies as compared to students who performed as individuals (mean rating = 4.0/5.0 and 3.4/5.0, respectively).

With this novel finding, and as the value of placing medical students in small teams during simulation activities is still relatively unexplored, we were interested in continuing to examine the impact of social learning context during NERVE engagement on outcomes with first-year medical students. The purpose of this study was to compare knowledge scores and perspectives between students interacting with NERVE VPs as individuals and students interacting with NERVE VPs as members of three-person teams.

Methods

Study population and educational context

This study occurred in conjunction with education related to the neuro-ophthalmological examination in the *Practice of Medicine* (P-1) module at the University of Central Florida (UCF) College of Medicine (COM). All 80 first-year medical students were required to participate in the activity as part of the MD program curriculum; however, consent to use data related to this study was voluntary. The study was approved by the UCF Institutional Review Board, and informed consent was obtained from students prior to participation. Students previously received instruction in basic neuroanatomy as part of the *Human Body: Structure and Function* module that integrates anatomy, embryology, histology, physiology and neuroscience.

Instructional design

NERVE simulation—The simulation included an interactive, self-paced tutorial to introduce rules for engaging NERVE, methods to enhance communication between users and VPs and guided instruction for performing physical examinations. Four cases were presented through NERVE to all students in the following sequence: Case 1 = non-CN-related visual abnormality; Case 2 = CN VII palsy; Case 3 = CN IV palsy; and Case 4 = CN VI palsy. Elements specific to each case, including VP avatars, history details and abnormal physical findings, were identical for all students.

Feedback modules—Feedback modules were designed by the authors to supplement NERVE with a review of clinical presentation and findings, introduction of new content and disclosure of the correct diagnosis (Figure 3). One module was created for each case using Articulate® Presenter, thereby allowing student access through web links embedded in online study instruments (described in the next section). Modules were accessible to students immediately following online submission of their proposed diagnosis for each patient.

Instruments

Five instruments were created by the authors, as described below (see Figure 4 for timing of use). Instruments were deployed online *via* SurveyMonkey™ and were completed by students on their COM-issued laptop computers.

Pre-training questionnaire—This four-item questionnaire requested students to identify age, gender, ethnicity and whether or not English is their primary language.

Self-assessment—This two-item tool measured perceived confidence related to general and CN case-specific history-taking skills as rated on a five-point Likert-type scale of agreement, where 1 = strongly disagree and 5 = strongly agree. The self-assessment was completed pre- and post-training.

Knowledge test—The knowledge test presented 12 multiple-choice items assessing knowledge related to early myasthenia gravis, and left and right CN IV, VI and VII palsies. Items were first pilot tested with 37 second-year medical students. Based on item analysis (Table 1), select items were deleted or revised, and new items were included on a subsequent version delivered to 57 first-year medical students. Item analysis further informed revisions for the version used in this study. The knowledge test was completed pre- and post-training. Pre- and post-test items were presented in random order, but all students encountered the same randomized version at each time of assessment.

Diagnosis form—The diagnosis form asked students to identify the CN palsy and side of injury demonstrated by the VP and directed the student to view the relevant feedback module. Diagnosis forms were presented following each of the four cases.

Student perspectives survey—This two-item survey asked students to speculate about preferences and perceived efficacy for the use of NERVE in alternate social learning contexts.

Procedure

The study was conducted at COM in two parts (Figure 4): Part 1 took place in a large lecture hall, and Part 2 occurred in small-group learning rooms and in the Clinical Skills and Simulation Center (CSSC), where private examination rooms are available to accommodate 12 three-person teams (team treatment, $n = 36$). Accordingly, students were assigned to social learning context treatments by means of restricted random assignment.

Part 1—All students worked individually to complete the first series of study instruments and to become acclimated to using NERVE. Following installation of NERVE on their COM-issued laptop computers, students viewed the tutorial and moved independently through the first case (non-CN-related visual abnormality). Students were permitted to work at their own pace; however, in general, students completed Part 1 in approximately 1–1.5 hours.

Part 2—Students were next assigned to computer workstations to interact with NERVE in their respective social learning contexts. All computers were previously installed with NERVE and three cases (CN VII, CN IV and CN VI palsies). Written instructions for participating in the team learning context were placed at the workstations in the CSSC examination rooms. Instructions encouraged students in teams to take turns operating NERVE for one case, and invited students to work together to discuss diagnoses, but asked students to complete the diagnosis forms and final set of instruments independently. All students were instructed to use their COM-issued laptop computers for individual completion of online study instruments. Students were permitted to work at their own individual or team pace; however, in general, students completed Part 2 in approximately 2–2.5 hours.

Statistical analysis

Categorical variables are reported as frequencies and percentages, and comparisons between categorical variables were made using chi-square or Fisher's exact tests. Descriptive statistics for Likert-type rating scale items are presented as median (minimum and maximum); within-group comparisons were made using Wilcoxon signed-ranks tests, and between-group comparisons were conducted with Mann–Whitney *U* tests. Continuous variables are presented as mean ± standard deviation, with 95% confidence intervals (CI) reported for the mean; within-group comparisons were conducted with paired samples *t*-tests, and between-group comparisons were made using independent samples t-tests, except as described below for knowledge test scores. All tests were two-sided, and p values <0.05 were considered statistically significant. Item analysis was performed on the knowledge test, where indices of difficulty are reported as proportion of students answering each item correctly, and indices of discrimination are represented by point-biserial correlations. Test reliability is described by Cronbach's coefficient alpha as an estimate of internal consistency. All statistical analyses were completed using SPSS 20.0 (IBM; Chicago, IL).

Knowledge test scores—Analysis of covariance was originally planned for comparing knowledge post-test scores between social learning contexts; however, heterogeneity of slopes suggested the presence of an ATI effect. That is, "treatments", or social learning contexts, appeared to have differential effects on students' post-test performance depending upon student "aptitude", or pre-test performance (Cronbach & Snow 1981; Pedhazur & Schmelkin 1991). Regression analysis confirmed the presence of a significant ATI effect. Accordingly, simultaneous regions of significance were calculated to identify the pre-test score ranges for which social learning contexts differed significantly on post-test scores. Calculations were based upon formulae constructed by Potthoff (1964) as a modification to the Johnson–Neyman approach (Aiken & West 1991; Pedhazur & Schmelkin 1991; D'Alonzo 2004). Follow-up independent samples *t*-tests were conducted to further describe the inferences of these calculations for a sub-set of the sample.

Results

Participants

Seventy-eight of 80 students (97.5%) consented to participate. Participants ranged in age from 20 to 32 years (24.6 ± 2.6 years; 95% CI = 24.0–25.2) and included 39 females (50.0%). Eight students (10.3%) reported that English is not their primary language.

Restricted random assignment resulted in 36 students assigned to the team treatment and 42 students assigned to the individual treatment. Students did not differ significantly between treatments based on age ($p = 0.28$), gender ($p = 0.82$) or primary language ($p = 1.00$).

Diagnosis of CN palsies

Percentage of students identifying the correct diagnosis for VPs did not differ significantly between treatments for Case 1 (non-CN-related visual abnormality), when all students interacted with NERVE as individuals ($p = 0.78$; team = 45.7%; and individual = 42.5%), or for Case 2 (CN VII palsy; $p = 0.11$; team = 86.1%; and individual = 70.7%). Correct diagnoses were provided by students in the team treatment significantly more often than by students in the individual treatment for Case 3 (CN IV; $p = 0.04$; team = 86.1%; and individual = 65.9%) and for Case 4 (CN VI; $p = 0.03$; team = 97.2%; and individual = 80.5%).

Knowledge test

Data were first screened for missing cases and extreme values; knowledge test scores were also explored for checking assumptions of statistical tests. One student in the individual treatment was excluded from analysis related to knowledge test scores due to missing pre-test data. An additional student from the individual treatment, identified as a bivariate outlier (on pre-/post-test scores), was excluded from this same analysis due to comparatively high leverage and influence on the regression solution. Accordingly, the sample for this analysis included 76 students (team, $n = 36$; individual, $n = 40$).

Learning—Students in both treatments demonstrated significant gains in knowledge from pre- to post-test. Mean test scores increased significantly in the team treatment from 60.6% to 80.1% ($p<0.001$; mean difference = 19.4%; 95% CI = 12.6–26.3), as well as in the individual treatment, from 53.8% to 77.3% ($p<0.001$; mean difference = 23.5%; 95% CI = 17.8–29.3).

Treatment differences—A visual examination of pre-/post-test score scatterplots suggested heterogeneity of regression slopes. As preliminary regression analysis confirmed a significant pre-test score by treatment interaction effect ($p = 0.04$), a modification of the Johnson–Neyman procedure was applied to determine the ranges of pre-test scores for which treatments differed significantly on post-test scores. The crossover point of regression lines occurred at a pre-test score of 57.0% (6.8 items), the lower bound of the region was 25.8% (3.1 items), and the upper bound of the region was 88.3% (10.6 items; Figure 5). Accordingly, at pre-test scores below 25.8%, students in the team treatment scored significantly higher on the post-test than did students in the individual treatment.

Conversely, at pre-test scores above 88.3%, the interpretation is that students in the individual treatment would begin to out-perform students in the team treatment on the post-test; however, the ceiling effect associated with student performance in this aptitude range renders this region of significance impractical for consideration here. Post-test scores did not differ significantly between treatments when pre-test scores occurred in the range of 25.8%–88.3%.

Ten students (team, n = 4; individual, n = 6) scored ≤25.8% on the pre-test. For these students, mean pre-test scores did not differ significantly between team and individual treatments (p = 0.81; 16.7% and 18.1%, respectively; Figure 6); however, as the simultaneous regions of significance identified, students in the team treatment scored significantly higher (66.7%) than did students in the individual treatment (43.1%) on the post-test (p = 0.03; mean difference = 23.6%; 95% CI = 3.6–43.6).

Item analysis—Ranges of difficulty and discrimination indices and estimates of test score reliability for the current sample are presented in the last two rows of Table 1. While all test items exhibited moderate to strong discrimination, two items demonstrated relatively poor improvement in difficulty from pre- to post-test. One item pertained to diagnosis of a CN VI palsy (pre-test difficulty = 0.42; post-test difficulty = 0.55), and one item pertained to diagnosis of a CN V palsy, which was covered only peripherally in the feedback module content (pre-test difficulty = 0.45; post-test difficulty = 0.55).

Student perspectives

Self-assessment—Student ratings of confidence in CN-specific history-taking skills increased significantly pre- to post-training in the team treatment (p<0.001; median rating = 2 [1, 5] and 4 [1, 5], respectively) and in the individual treatment (p<0.001; median rating = 3 [1, 4] and 4 [2, 5], respectively). Confidence ratings between treatments did not differ significantly pre-training (p = 0.13) or post-training (p = 0.52). Student ratings of confidence in general history-taking skills did not change significantly pre- to post-training in the team treatment (p = 0.41) or in the individual treatment (p = 0.18), and ratings did not differ significantly between treatments pre-training (p = 0.21) or post-training (p = 0.65; all median ratings = 4).

Preference to use NERVE in alternate social learning context—Post-training, students were asked, “Based on your experience in today’s training, do you think you would have preferred to utilize NERVE as a member of a small team of your peers/on your own?” as applicable to each treatment. A significantly greater percentage of students who participated in the individual treatment (42.9%) indicated the desire to utilize NERVE as a member of a small team, as compared to the percentage of students who participated in the team treatment (30.6%) indicating a desire to utilize NERVE independently (p = 0.02).

Preference for social learning context and curriculum timing—Post-training, students responded to the question, “How do you feel the NERVE simulation exercises could be most effectively integrated within the medical curriculum?” by ranking their top three choices from among the following six options:

- As a take-home exercise in year 1
- As an individual laboratory exercise in year 1
- As a team laboratory exercise in year 1
- As a take-home exercise at the start of year 2
- As an individual laboratory exercise at the start of year 2
- As a team laboratory exercise at the start of year 2

Students predominantly ranked “as a team lab exercise in year 1” as the first choice, regardless of the social learning context in which they interacted with NERVE (team = 48.6%; individual = 34.1%).

Discussion

CN palsies are relatively uncommon, often resulting in delays in diagnosis with suboptimal patient outcomes. These delays are problematic, as the most frequent causes of CN palsies require immediate medical attention. Due to their rare presentation, exposure to patients with CN palsies is difficult to provide in educational settings.

NERVE was developed to address this need by affording students opportunities to practice history-taking, physical examination and diagnosis of patients with CN palsies in a virtual environment. Our investigation into the use of NERVE VPs as teaching tools indicated that simulated systems may appropriately fill this gap in the curriculum. Overall, first-year medical students who participated in this study demonstrated significant increases from pre- to post-training in ratings of confidence in their history-taking skills specific to patients with CN palsies. Students also made significant gains in knowledge related to CN palsies from pre- to post-training, and they correctly diagnosed patients with CN palsies 74%–87% of the time, exceeding the rate of 53% that has been observed among a sample of neurology clerkship students (Davis & King 2007).

Based on findings related to social learning context, we are inclined to implement NERVE experiences in small team contexts with medical students in the future. Subjectively, students recommended integrating future NERVE exercises into the curriculum as team laboratory activities more than any other curriculum delivery mode, regardless of whether they worked through NERVE in the current study as individuals or as team members. Furthermore, 42.9% of students who participated as individuals indicated a desire to use NERVE as a member of a small team. Objectively, a significantly greater percentage of students in the team treatment correctly diagnosed the VPs with CN IV and VI palsies, as compared to students in the individual treatment. Moreover, a significant ATI effect identified that students in the team treatment attained a mean post-test score approximately 24% higher than students in the individual treatment at specific aptitudes. Johnson et al. (2013) observed this same ATI effect with 57 second-year medical students; at pre-test scores ≤50%, students in the team treatment scored significantly higher (21%) on the knowledge post-test as compared to students in the individual treatment.

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Based on Vygotsky's (1978) concept of zone of proximal development, we suspect that lower aptitude students demonstrated significant gains in knowledge post-test scores because they worked in teams with at least one higher aptitude student. Higher aptitude students likely provided scaffolding to assist lower aptitude students with content knowledge and skills that they otherwise did not possess (Wood & Middleton 1975; Wood et al. 1976). Accordingly, we recognize the importance of determining if students in homogeneous teams (specifically all members with lower aptitudes) derive similar learning benefits and/or the importance of purposely forming heterogeneous teams based on student aptitude scores. Medical educators must then devote attention to extending opportunities for educational value to higher aptitude students engaged in team learning contexts with NERVE. Although we defined aptitude in this study as prior content knowledge, it is also important to investigate how other constructs reflective of aptitude (e.g. motivation and learning style) interact with treatments in medical education (Cook et al. 2009, 2011).

Limitations

Research conclusions may be limited in generalizability due to study-specific factors. Study participants were at a specific point in the curriculum at a single medical education institution. In addition, NERVE presented four specific CN palsy cases with exposure to tailored case-related feedback to supplement the learning experience. Finally, the knowledge test was designed to match objectives of the P-1 module activity and content addressed by NERVE; an increase in number of test items may be necessary to improve internal consistency.

Directions for future research

Expanding upon the scope of content and cases embedded in NERVE, simulation system developers have created a version of NERVE that allows users to conduct a physical examination of VPs presenting with any one or more of 12 CN palsies (CN I to CN XII). Depending upon the CN palsy portrayed by the VP, virtual tools are available in the system to allow students to observe abnormal physical findings associated with sensory responses (e.g. smelling a bar of soap; feeling a sharp object; and hearing the sound of a tuning fork), eye movements (e.g. following a physician's finger) and facial and body movements (e.g. smiling; shrugging shoulders; and leaning forward). Users have control to assign any combination of disorders to the VP by selecting the CN(s) to be injured and by assigning the injury to the left, right or both sides. This control allows users to explore a variety of patient scenarios and to observe a wide range of abnormal physical findings in a self-directed manner. While our findings from this study and results from Johnson et al. (2013) suggest that NERVE exercises may best be implemented in small collaborative team contexts, we recognize that the strain on medical education resources may challenge educators to successfully plan for such activities. Limited small-group learning spaces in institutional facilities and restrictions on contact hours allowed in the curriculum may necessitate a selection of self-directed, individualized learning opportunities. Further investigation into optimal use of both systems in the curriculum is warranted, as the ultimate goal is to deliver NERVE to the medical education community as an open-access resource with well-defined and established guidelines for best practices associated with its use.

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Practice points

- Simulated environments allow medical students to practice examination skills without risk of patient harm.
- Virtual patients (VPs) offer valuable alternative encounters when live patients with rare and complex conditions, such as cranial nerve (CN) palsies, are unavailable.
- Students who interacted with VPs as members of three-person teams diagnosed CN palsies correctly more often than did students who interacted with VPs as individuals.
- At comparatively lower aptitudes, students in the team learning context demonstrated significantly greater learning gains than did students in the individual learning context.
- Attention should be devoted to determining optimal social learning contexts in which medical educational activities are organized, particularly as there is the potential for aptitude-treatment interaction effects with use of simulation systems.

NERVE = Neurological Examination Rehearsal Virtual Environment; VP = Virtual Patient

Figure 1.
Use of virtual physician hand with NERVE VP.

NERVE = Neurological Examination Rehearsal Virtual Environment; VP = Virtual Patient

Figure 2.

NERVE VP responds to user-typed directive.

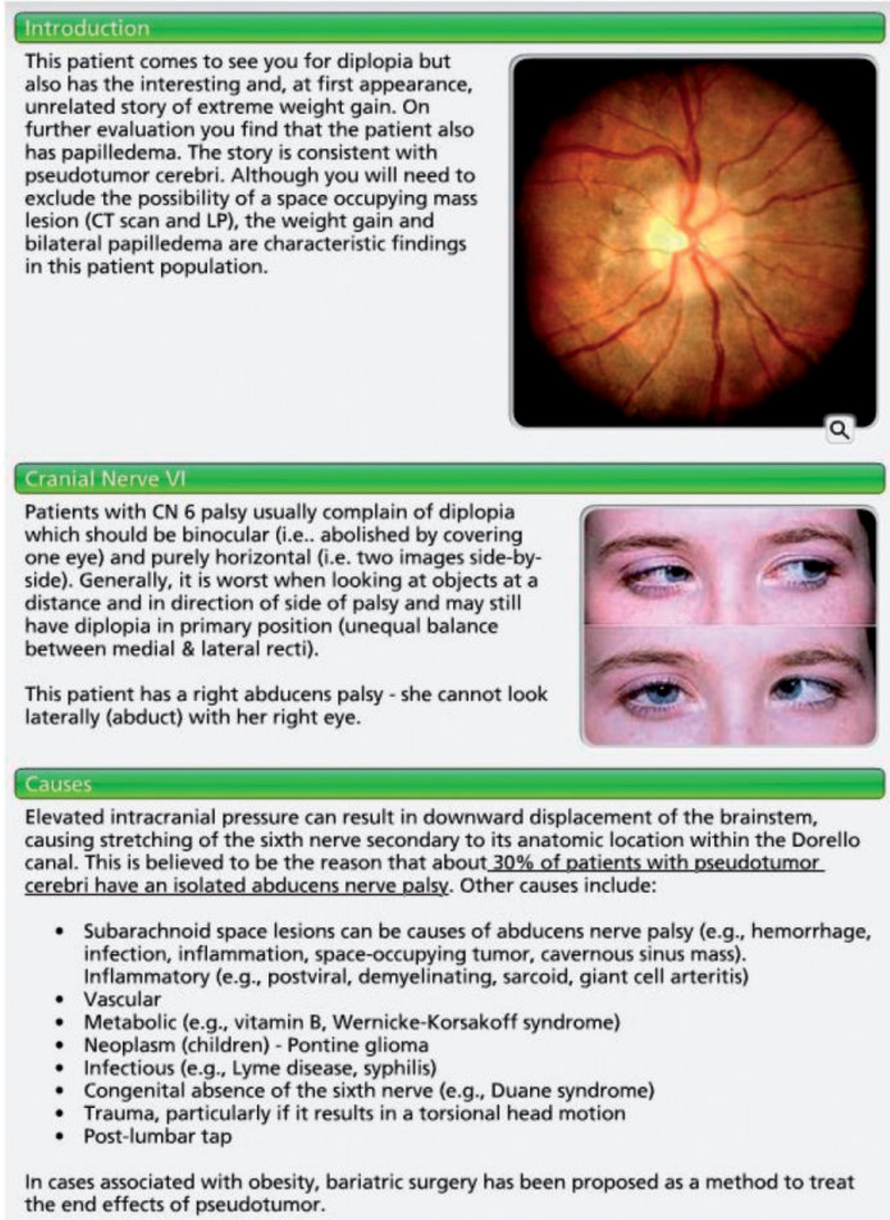

Figure 3.

Example Articulate® presenter feedback module.

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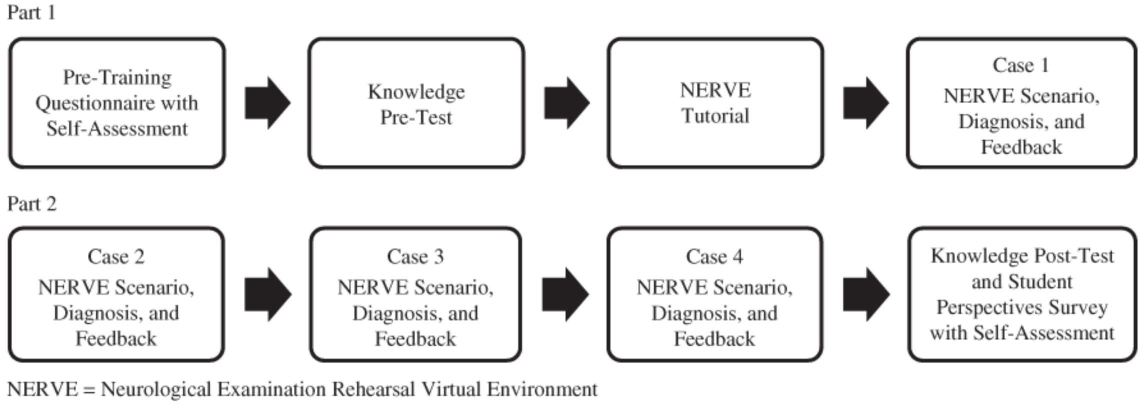


Figure 4.
Research procedure.

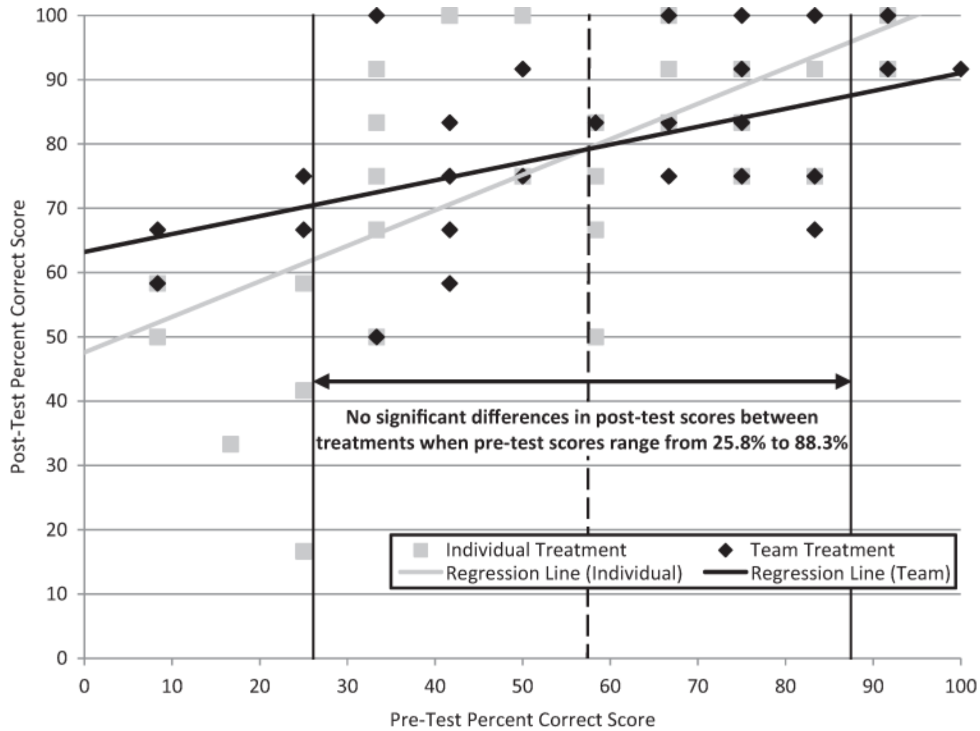
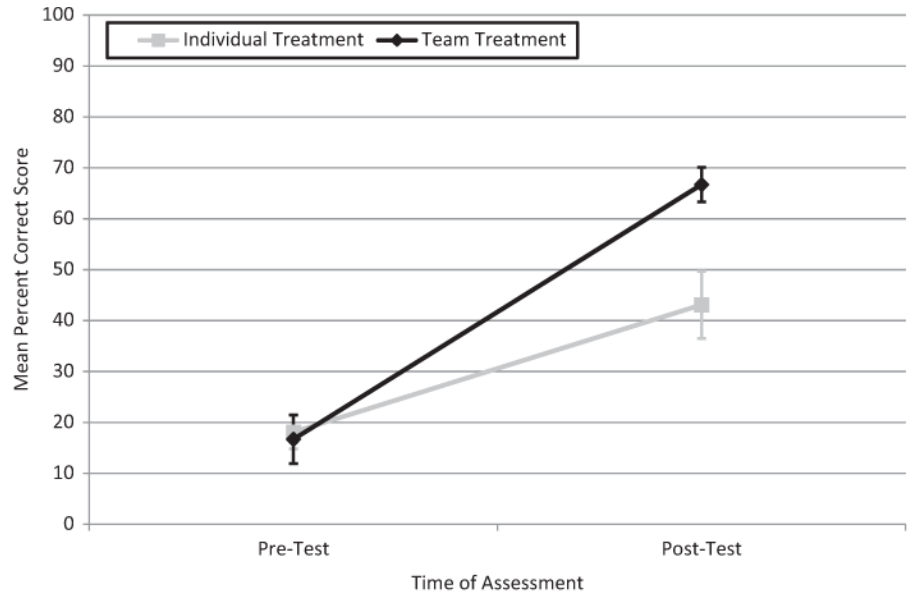


Figure 5.

Pre-/post-test score scatterplot by treatment: Disordinal interaction with simultaneous regions of significance and crossover point defined.



Error bars represent one standard error above and below the mean

Figure 6.

Mean pre-/post-test scores by treatment for students who scored ≤ 25.8% at pre-test.

Table 1

Item analysis summary for knowledge test.

Medical students tested	Time of assessment	Difficulty (index range)[a]	Discrimination (index range)[b]	Internal consistency (Cronbach's α)
37 second-year	Pre-test	0.57–1.00	0.00–0.75	0.25
	Post-test	0.56–0.97	−0.02–0.63	0.42
57 first-year	Pre-test	0.30–0.91	−0.26–0.73	0.56
	Post-test	0.27–0.96	0.00–0.73	0.62
76 first-year	Pre-test	0.42–0.76	0.35–0.68	0.71
	Post-test	0.55–0.90	0.22–0.68	0.57

[a]Index of difficulty = proportion of students answering item correctly.

[b]Index of discrimination = point-biserial correlation.