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Physical Fidelity Versus Cognitive Fidelity Training in Procedural Skills Acquisition

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Objective: The current study examined whether training simulators for the acquisition of procedural skills should emphasize physical fidelity or cognitive fidelity of the task.

Background: Simulation-based training for acquiring and practicing procedural skills is becoming widely established. Generally speaking, these simulators offer technological sophistication but disregard theory-based design, leaving unanswered the question of what task features should be represented in the simulators. The authors compared real-world training and two alternative virtual trainers, one emphasizing physical fidelity and the other cognitive fidelity of the task.

Method: Participants were randomly assigned to one of four training groups in a LEGO® assembly task: virtual-physical fidelity, cognitive fidelity, real world, and control. A posttraining test to assess the development of procedural skills was conducted.

Results: Both the virtual-physical fidelity and cognitive fidelity training methods produced better performance time than no training at all, as did the real-world training. The cognitive fidelity training was inferior in terms of test time compared to the real-world training, whereas the virtual-physical fidelity training was not. In contrast, only the real-world and the cognitive fidelity groups, and not the virtual-physical fidelity group, required significantly less time than the control group for error correction.

Conclusion: The two training methods have complementary advantages.

Application: Combining physical fidelity and cognitive training methods can enhance procedural skills acquisition when real-world training is not practicable.

Keywords: trainers, virtual reality, human factors, transfer of training

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Procedural skill is the ability to execute action sequences to solve problems (Rittle-Johnson, Siegler, & Alibali, 2001)—or, put more simply, "knowing how to do things" (Annett, 1996). Procedural skill reflects knowledge of *how* and *when* to perform the procedures needed to accomplish a given task, whether simple or complex. For example, in a maintenance and assembly task, procedural skill requires the operator to have a mental representation of the task organization: how many steps are needed, what should be done at each step, and in what order the steps must be performed to efficiently assemble or disassemble a device or remove a broken part.

Most researchers agree that procedural skill develops as a result of practice through repeated exposure to a certain task (e.g., Gupta & Cohen, 2002). This notion has been applied in many real-world fields that involve procedural tasks. Procedural training for Alzheimer's patients, for example, involves stimulation of procedural memory through the repetitive performance of everyday activities (Farina et al., 2002). Surgeons acquire procedural skills primarily through "training by doing" (Kneebone, 2003).

The past decade has seen increasing use of virtual simulators for operators who need to acquire or practice procedural skills—for instance, in the fields of laparoscopic surgery (Dawson, 2006), bronchoscopy (Colt, Crawford, & Galbraith, 2001), and industry and maintenance (Claessens, Min, & Moonen, 2000; Johnson & Rickel, 1997). The ultimate goal of any virtual training system is to provide enhanced performance in the real-world task (Lathan, Tracey, Sebrechts, Clawson, & Higgins, 2002), a process known as transfer of training. Transfer of training refers to the process by which knowledge, skills, and abilities acquired through training are applied in the actual situation (Baldwin & Ford, 1988). Given that procedural skills are likely to be specific to a certain task, and given that such skills are acquired through repeated practice, ensuring that a training simulation resembles the actual task is likely to be important for successful transfer. Similar notions about the necessary resemblance between the research and the natural environment were considered by Hoffman and Deffenbacher (1993), who defined four types of relations: ecological *validity* (materials, tasks, and setting preserve natural forms), ecological *relevance* (things that people actually perceive or do), ecological *salience* (*important* things that people perceive or do), and ecological *representativeness* (things that people *often* perceive or do).

However, there are two general approaches to ensure the resemblance between the training simulator and the actual task. Under the first approach, originally proposed by Thorndike and Woodworth (1901), transfer from the first task (the simulation) to the second, real-world task occurs most efficiently when the two tasks have identical component activities. The more elements that are shared between the two tasks, the better the transfer (Baldwin & Ford, 1988). This "identical elements" principle emphasizes the importance of physical fidelity, defined as the degree to which the simulation looks, sounds, and feels like the actual task (see Alexander, Brunyé, Sidman, & Weil, 2005).

The centrality of physical fidelity is supported by the ecological approach of perception and action (see Chemero, 2003; Gibson, 1986; A. Stoffregen, 2003; Turvey, 1992). According to this approach, perception is primarily determined by *affordance*, which can be described as the set of potential behaviors available to an individual in a given situation and environment (Norman, 1998; T. A. Stoffregen, Bardy, & Mantel, 2006). According to T. A. Stoffregen et al. (2006),

> In the Ecological Approach, perceptual guidance of action and the resultant emergence of cognition are possible because properties of the animal-environment system are specified in a potential sensory stimulation, where specification consists of lawful, 1:1 relations between static and dynamic properties of the animal-environment system and patterns in ambient energy arrays. (p. 5)

Hence, from this perspective, transfer of training is dependent on the physical similarity between the simulator and the real world, and cognitive mechanisms to mediate between perception and action are not necessary. Today, many simulator designers work under this principle, aiming to make their training simulators replicate the real-world task to the greatest degree possible (on the "specificity of practice" hypothesis, see Liu, Blickensderfer, Macchiarella, & Vincenzi, 2009; Proteau, Marteniuk, & Lévesque, 1992).

The second approach also sees fidelity as key to effective simulator training transfer, but neither physical fidelity nor technological sophistication is central to this view. Instead, this approach holds that the simulator should incorporate high *cognitive fidelity* (Lathan et al., 2002) with regard to the actual task. Cognitive fidelity refers to the extent that the simulator engages the trainee in the types of cognitive activities involved in the real-world task (Kaiser & Schroeder, 2003). This approach does not require duplication of physical elements. In contrast, it is assumed that transfer of training can be obtained through training tasks and aids that do not necessarily replicate the real-world task but that do maintain the correct stimulus–response relationship (Lathan et al., 2002). For instance, a cockpit simulator that requires a high level of attention from the pilot (stimulus) and produces psychological effects such as stress and workload (response) is considered to have high cognitive fidelity because it duplicates the cognitive situation in the real-world system, in which the pilot should monitor several systems and plans concurrently.

Under the cognitive fidelity approach, if the level of fidelity captures the critical properties of the task one wishes to train, that level of fidelity is sufficient even if the specific actions practiced noticeably deviate from those of the real-world task (Alexander et al., 2005). There is some evidence that this approach can work. For instance, Gopher, Weil, and Bareket (1994) studied the use of a low-physical-fidelity, microprocessor-based simulator of a flight task to train flight cadets in attention management skills. Their results showed a 30% increase in actual flight scores of Israel

Air Force cadets after a 10-hr training program. Findings from research in sport psychology (Farrow, Chivers, Hardingham, & Sacuse, 1998; Williams, Ward, & Chapman, 2003) similarly suggest that applying a training method that incorporates key perceptual-cognitive components is likely to improve performance in both the simulation task and the actual real-world task (for a review, see Ward et al., 2008).

Cognitive fidelity in simulation training for procedural skills acquisition can be achieved by designing the simulator to support motor imagery. In its most basic definition, motor imagery is a process in which the individual imagines self-performed action (Annett, 1995; Jeannerod, 1997). Jacobson (1930) found micromovements and electromyographic activity in the limbs involved in imagined movements. Chao, Haxby, and Martin (1999) found that viewing and naming pictures of tools selectively activated premotor areas, even in the absence of any subsequent motor activity. Researchers have employed several different methods for creating motor imagery. The most common motor imagery manipulation in cognitive psychology involves giving the subject a task or problem that calls on imagery processes for its solution. Another method is to elicit a verbal protocol by asking the subject to—for example— "describe in as much detail as they can how to tie two ends of string together to make a bow" (Annett, 1986).

As this brief description shows, there are some empirical data and theoretical grounding behind emphasizing physical fidelity to make a training simulator resemble the actual task and to enhance procedural skills transfer, and the same is true for emphasizing cognitive fidelity, too. Yet designers of training simulators for procedural skills acquisition still lack solid evidence to substantiate the choice of one approach over the other, or indeed of either as compared to real-world training.

In the current study we compare real-world training and two alternative virtual trainers, one based on physical and the other on cognitive fidelity, for procedural skill acquisition in a LEGO® assembly task. For this purpose we chose a real LEGO® model requiring 75 steps. Four training sessions with the virtual trainers were followed by a test in which participants constructed the actual model. One of the virtual trainers employed a 3-D manipulation environment that allowed trainees to perform the steps virtually but without haptic feedback; it thus emphasized physical fidelity of the task. The other required participants to verbally describe each step and the parts involved based on a diagram (a variant of motor imagery), and so emphasized cognitive fidelity of the task. The study design allowed us to compare the two virtual training methods to each other and to real-world training based on participants' performance over the training sessions and in the real-world test. We hypothesized that a training method emphasizing either physical fidelity or cognitive fidelity of a procedural task would aid in skill acquisition even in the absence of physical practice.

METHOD

Design

The procedural task chosen for this study was assembling by hand a LEGO® model using an instruction manual with step-by-step diagrams of the 75 assembly stages, where each diagram includes a picture of the LEGO® bricks needed for that stage and the current view of the model. Participants were randomly assigned to virtual-physical fidelity, cognitive fidelity, real-world and control training conditions. The virtual-physical fidelity condition involved virtually "building" the LEGO® model using the LEGO Digital Designer© computer program and the instruction manual. The cognitive fidelity training consisted of active visualization and verbalization of the different assembly stages for the same LEGO® model using a computer program called "Helicopter" specially developed for this study (see the "Materials and Procedure" section). Both sets of trainees completed the training program four times. The performance of these two experimental groups was compared to that of two benchmark groups. Participants in the real-world training group built the LEGO® model four times by hand using the instruction manual before building it under test conditions. Those in the control group received no training of any kind.

Participants

A total of 59 undergraduate students (29 males, 30 females) from Technion–Israel Institute of Technology served as participants. In all, 19 participants (9 males, 10 females) were randomly assigned to the virtual-physical fidelity group and 20 (10 males, 10 females) to the cognitive fidelity group. The remaining 20 (10 males, 10 females) made up the control and real-world groups as follows: All 20 participants built the model by hand four more times, making a total of four training sessions, followed by a final test. The first training session of a random sample of 10 of them (5 males, 5 females) served as a control. This was possible because participants in all training sessions were told to complete the task as quickly as possible. The remaining sample of 10 participants (5 males, 5 females) made up the real-world group.

The participants' average age was 24.05, with a range of 19 to 29. None had experience with the specific task used in the experiment, but 35.59% had some experience with LEGO® model assembly. Only 16.95% had prior experience with computerized LEGO® model assembly. All participants were paid a fixed amount of New Israeli shekels (NIS) 40 (about US$10) per hour for their participation.

Materials and Procedure

Participants in all training conditions completed the training task four times. Each time they were instructed to complete the task as quickly and accurately as possible (with all the bricks in their correct places at the end of the assembly). Participants received bonuses according to their performance in each session: NIS 20 (about US$5) to the participant who built an accurate (real or virtual) model in the shortest time and NIS 10 (about US$2.50) to the three participants who finished second, third, and fourth. On the following day, members of all three groups constructed by hand the real LEGO® model, with similar instructions, the same instruction manual used in the training, and similar bonuses. Participants received instructions about each individual session when they performed it. They were not told how many times they would be asked to construct the model or given any further information about the study procedures or goals.

The training sessions were conducted as follows:

Virtual-physical fidelity training. Participants were asked to "build" the LEGO® model using the LEGO Digital Designer© (Havok. Com Inc., 2008) computer program, following the instruction manual. The program screen was divided into a palate containing all the LEGO® bricks needed for the model and an assembly area. To complete a given assembly stage, trainees had to choose the correct LEGO® brick from the palate and drag it to the correct location as depicted in the instruction manual. The relative sizes of the palate and assembly area could be adjusted by the trainees. Trainees were also able to carry out different manipulations such as zooming in and out, changing the point of view, moving the LEGO® bricks within the assembly space, changing the bricks' position from horizontal to vertical and vice versa, and so on (see Figure 1).

Cognitive fidelity training. Participants in this group were shown the diagrams of the different assembly stages on the computer screen and were required to describe the stages verbally. For each assembly stage, the program presented the relevant diagram taken from the instruction manual. The screen was divided into a large space for the diagram and a "description area" composing two fields: a "name field" for the name of the brick to be added to the model in that stage and a "place field" in which to describe the brick's location relative to other bricks already in the model. Cards given to the participants in advance showed each brick with its name clearly labeled. The program allowed trainees to continue to the following assembly stage only after accurately completing these two fields, with a minimum of 15 characters in the description field. If an incorrect part name was given, or if the description composed fewer than 15 characters, the program presented an error message that prevented participants from moving on until the appropriate correction was made. Participants could go back when they wished to see prior assembly stages (see Figure 2).

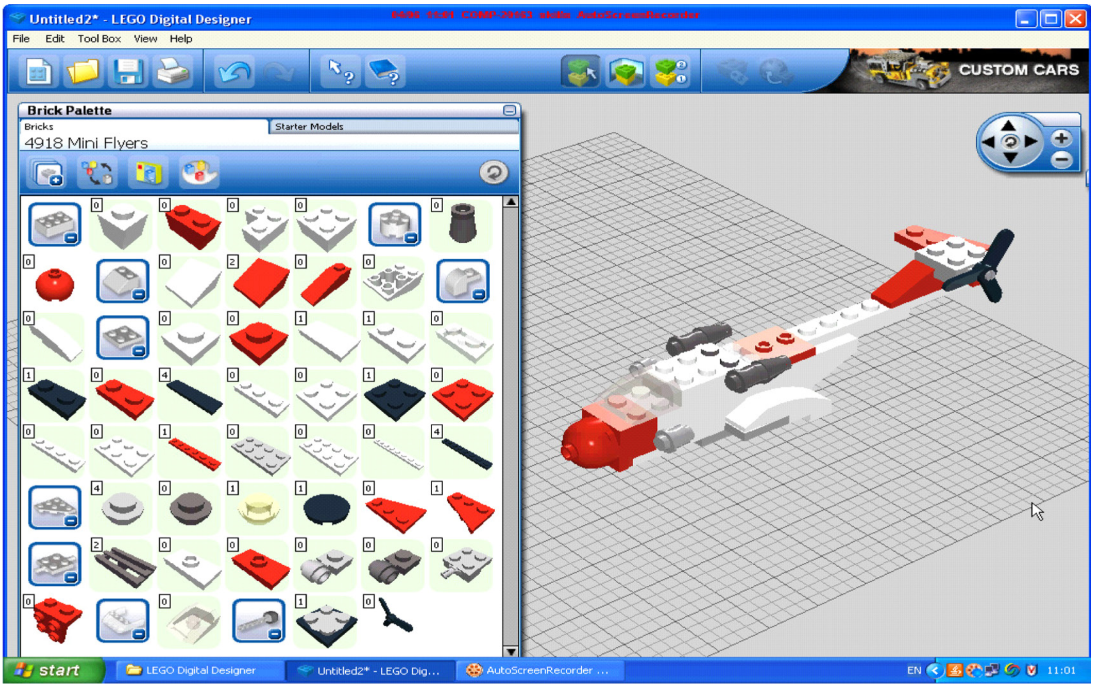

Figure 1. A screenshot from the LEGO Digital Designer© system used for the virtual-physical fidelity training group.

Real-world training and control. Participants in the real-world and control groups assembled the real LEGO® model during all training sessions, using the instruction manual.

Procedure

The experiment took place in the Multimodal Interfaces for Capturing and Transfer of Skill (SKILLS) laboratory of the Research Center for Work Safety and Human Engineering at Technion. The experiment lasted 2 days.

Day 1

Virtual-physical fidelity and cognitive fidelity groups. Participants were invited in groups of five and given a short general introduction to the experiment and the task. They were then given a set of cards with detailed instructions on how to use the relevant computer program (LEGO Digital Designer© for the virtual-physical fidelity group and Helicopter for the cognitive fidelity group) and a set of sample task instructions. The cognitive fidelity group received an additional set of cards showing the LEGO® bricks with their names clearly labeled, organized by shape. Participants were asked to carefully read the program instructions and then proceed to the sample task, which consisted of a five-brick model to be completed according to the procedures for the relevant group (virtually building the model in the virtual-physical fidelity group and describing the five assembly stages in the cognitive fidelity group).

Participants were asked to call the experimenter after completing the sample task to proceed to the next step. The experimenter then gave the participant written instructions for the first training session. These instructions included all information needed to complete the training session as well as a description of the bonuses policy. The experimenter confirmed that the participant had read and understood the instructions before allowing the participant to begin the training session.

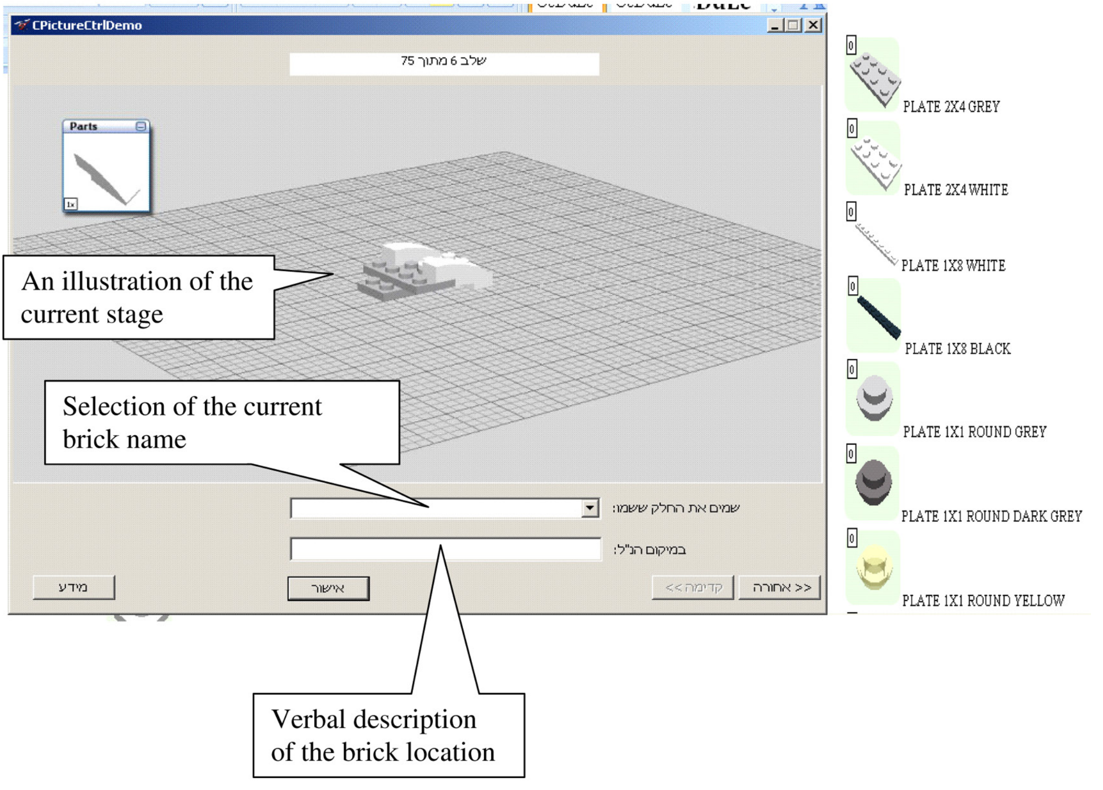

Figure 2. A screenshot from the “Helicopter” program used for the cognitive fidelity training group.

As each participant completed the first training session, the experimenter handed over the instructions for the second session, which was identical to the first. The third and fourth sessions were conducted similarly. Altogether participants had to virtually build and describe the LEGO® model four times, without knowing this in advance.

Once the participant had completed all four stages, he or she was thanked, debriefed, and reminded to return the following day. Participants were debriefed regarding the first day only and were told that instructions for the second day would be given at the appropriate time.

Real-world and control groups. Participants were invited individually to hear a short introduction to the experiment and the bonuses policy. Then each participant was asked to build the LEGO® model by hand using the instruction manual. The test session was filmed for data analysis purposes; participants were informed that the films were for research purposes only. The procedure at this point was similar to that for the virtual-physical fidelity and cognitive fidelity conditions. That is, once the participant finished assembling the model, the experimenter described the following stage, which was identical to the first session. The third and fourth training sessions were conducted in the same manner. Altogether participants in the real-world and control groups had to assemble the LEGO® model four times, although for the control group only the first session data were analyzed. Having completed the fourth session, participants were thanked and were reminded to return the next day, when they would be given instructions for that part of the experiment.

Day 2

The second day was identical for participants from all three groups. The experimenter invited participants individually and described

TABLE 1: Summary of Results: Means and Standard Deviations for Each Performance Measure

	Training Time (minutes)		Test Time (minutes)		Number of Final Errors		Number of Corrected Errors		Time Allocated to Error Correction (minutes)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control			19.7	5.6	1.8	1.3	4.4	2.2	2.9	2.8
Real world	39.2	8.7	7.0	1.0	0.9	0.9	1.5	1.6	0.3	0.4
Virtual-physical fidelity	59.0	14.0	10.3	3.0	0.6	1.2	2.2	1.5	1.6	2.0
Cognitive fidelity	163.6	43.5	12.1	5.0	0.9	1.1	2.0	1.7	1.0	1.4

the posttraining test task and the bonuses policy. As in the training sessions, participants were required to build the LEGO® model as quickly and accurately as possible.

The posttraining test session was filmed for data analysis purposes. Participants were informed that the films were for research purposes only.

Participants then filled out the demographic questionnaire. Finally, they were paid and thanked for their participation.

Performance Measures

Training time. Training time was the total time needed to complete the four training sessions.

Test time. Test time was the performance time in the posttraining test session (during the second day) for the virtual-physical fidelity, cognitive fidelity, and real-world groups. For the control group, test time was measured as performance time in the first training session (which counted as a test session for this group).

Number of final errors. The number of final errors was the number of bricks assembled incorrectly or left unassembled at the end of the test session.

Number of corrected errors. The number of corrected errors was the number of errors identified by the participant and corrected during the test session.

Time allocated to error correction. The time allocated to error correction was measured from the moment the participant disassembled a given LEGO® brick till the moment he or she was ready to move on to the next assembly stage.

RESULTS

General Summary

The results of the various performance measures for each group are depicted in Table 1.

Training Time

Training time was analyzed with ANOVA and was found to differ significantly among the virtual-physical fidelity, cognitive fidelity, and real-world groups, $F(2, 46) = 85.703$, $p < .001$, partial $\eta^2 = .788$. Post hoc comparisons with Bonferroni correction showed that the mean training time for the real-world group, 39.2 min, was significantly shorter than that for the cognitive fidelity group, 163.6 min ($p < .001$), but was not significantly shorter than the mean training time for the virtual-physical fidelity group, 59.0 min ($p = .279$). The mean training time for the virtual-physical fidelity group was significantly shorter than that for the cognitive fidelity group ($p < .001$). In summary, training time was relatively similar for the real-world and virtual-physical fidelity groups, but was significantly longer for the cognitive fidelity group. The mean training times are presented in Figure 3.

In addition, training times for the four training sessions were analyzed using repeated-measures ANOVA, with the training group (real world, virtual-physical fidelity, and cognitive fidelity) as the between-participants variable and the session number (from 1 to 4) as the within-participants variable. Training time was found to differ significantly between the sessions, $F(3, 138) = 79.611$, $p < .001$,

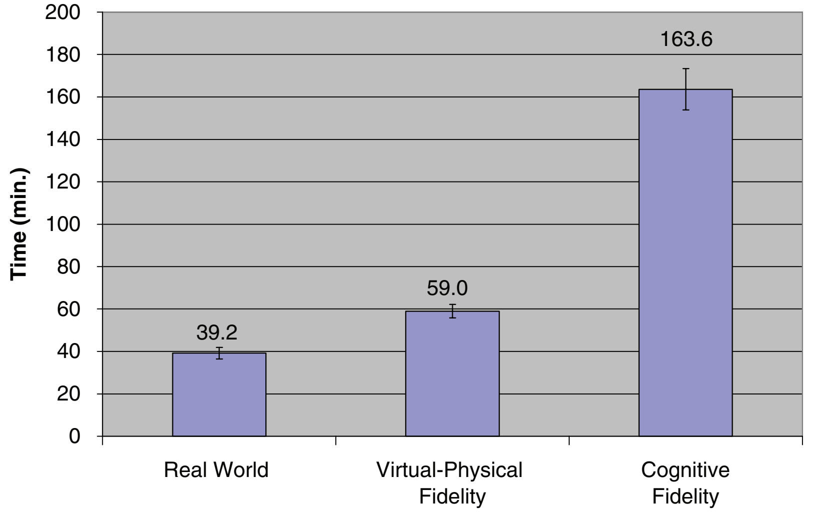

Figure 3. Mean training time and standard errors in the real-world, virtual-physical fidelity, and cognitive fidelity groups.

partial $\eta^2 = .634$, decreasing from the first to the forth session. Post hoc comparisons with Bonferroni correction showed that the mean training time in the first session, 38.7 min, was significantly shorter than in the second session, 24.0 min ($p < .001$), but the differences between the mean training time in the second and third (18.5 min) sessions ($p = .699$) as well as between the third and the forth (16.4 min) sessions ($p = 1.000$) were not significant. The effect of training group was significant, $F(2, 46) = 85.703$, $p < .001$, partial $\eta^2 = .788$, as was the interaction between session number and training group, $F(2, 46) = 85.707$, $p < .001$, partial $\eta^2 = .788$: The difference between the training groups was larger at the beginning of the training and decreased with the progress in training sessions. It is also interesting to note that, as expected, in Session 1 the mean time of the control group, 19.7 min, was not significantly different from the mean time of the real-world group, 16.2 min, $t(18) = 1.448$, $p = .165$, partial $\eta^2 = .104$, as the two groups had an identical experimental procedure. Mean training times in the four sessions are presented in Figure 4.

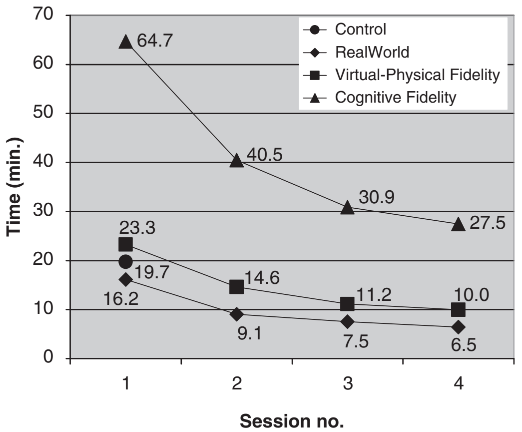

Figure 4. Mean training times and standard errors in the four training sessions in the control, real-world, virtual-physical fidelity, and cognitive fidelity groups.

Statistic Analysis of Test Time, Number of Final Errors, Number of Corrected Errors, and Time Allocated to Error Correction

A MANOVA with the training group (control, real-world, virtual-physical fidelity, and cognitive

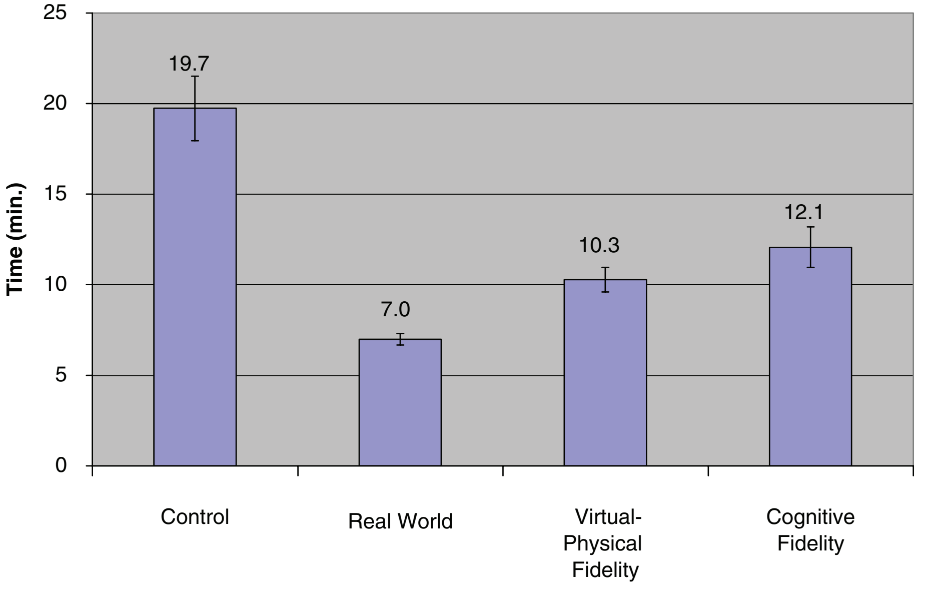

Figure 5. Mean test time and standard errors in the control, real-world, virtual-physical fidelity, and cognitive fidelity groups.

fidelity) as the between-participants independent variable, and test time, number of final errors, number of corrected errors, and time allocated to error correction as the dependent variables, was conducted. The effect of training group was significant, Wilks's Lambda test on the combined variable, $F(12, 138) = 5.378$, $p < .001$, partial $\eta^2 = .287$. In addition, a positive significant correlation was found among almost all of the performance measures: test time, number of final errors, number of errors, and time allocated to error correction. However, no significant correlation was found between the number of final errors and time allocated to error correction (see Table 2). Reported below are the univariate results of all performance measures excluding the number of corrected errors (which was found to be highly correlated with the time allocated to error correction).

Test Time

According to the MANOVA, test time was found to be significantly different between the groups, $F(3, 55) = 17.873$, $p < .001$, partial $\eta^2 = .494$. Post hoc comparisons with Bonferroni correction showed that the mean test time of the control group, 19.7 min, was significantly longer than the mean test time of the real-world (7.0 min, $p < .001$), virtual-physical fidelity (10.3 min, $p < .001$), and cognitive fidelity (12.1 min, $p < .001$) groups. The real-world group had a significantly shorter mean test time compared with the cognitive fidelity group ($p = .014$). The difference between the real-world and virtual-physical fidelity groups was not significant ($p = .275$), nor was the difference between the virtual-physical and cognitive fidelity groups ($p = 1.000$). In summary, training in all groups shortened test time, but the real-world group had an advantage over the cognitive fidelity group (see Figure 5).

Number of Final Errors

The number of final errors was not significantly different between the groups, $F(3, 55) = 2.405$, $p = .077$, partial $\eta^2 = .116$, although close to significance. Post hoc comparisons with Bonferroni correction showed that the only close-to-significant difference was between the control (M = 1.8 errors) and virtual-physical fidelity groups (M = 0.6 errors, $p = .067$).

TABLE 2: Correlation Matrix for the Performance Measures

	Test Time		Number of Final Errors		Number of Corrected Errors		Time Allocated to Error Correction	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Test time	1		.441**	<.001	.646**	<.001	.738**	<.001
Number of final errors	.441**	<.001	1		.298*	.022	.217	.099
Number of corrected errors	.646**	<.001	.298*	<.001	1		.710**	<.001
Time allocated to error correction	.738**	<.001	.217	.099	.710**	<.001	1	

*Significant at the .05 level, two-tailed. **Significant at the .01 level, two-tailed.

Time Allocated to Error Correction

Significant differences emerged in the time allocated to error correction, $F(3, 55) = 3.930$, $p = .013$, partial $\eta^2 = .177$. Using post hoc comparisons with Bonferroni correction, we found that the mean time allocated to error correction was significantly longer for the control group, 2.9 min, compared to the real-world group, 0.3 min ($p = .014$), and almost significantly longer compared to the cognitive fidelity group, 1.0 min ($p = .051$). The difference between the control and virtual-physical fidelity groups (1.6 min) was not significant ($p = .450$), nor was the difference between the real-world and virtual-physical fidelity groups ($p = .422$), the real-world and cognitive fidelity groups ($p = 1.000$), and the virtual-physical and cognitive fidelity groups ($p = 1.000$; see Figure 6).

DISCUSSION

Simulation-based training is becoming widely established in the domain of procedural skill acquisition in psychomotor tasks (Claessens et al., 2000; Colt et al., 2001; Dawson, 2006; Johnson & Rickel, 1997). However, there is a lack of research on how to best train procedural skills in psychomotor tasks. Since procedural skills are acquired through repeated exposure to a certain task (Gupta & Cohen, 2002), it is important to determine whether this task should be physically or cognitively represented within the simulator. The physical fidelity approach claims that the simulator should replicate the real-world task to the greatest degree possible (see Alexander et al., 2005; Liu et al., 2009). In contrast, the cognitive fidelity approach states that the simulator should engage the trainee in the type of cognitive activities involved in the real-world task, without needing to duplicate the physical elements of the task (Alexander et al., 2005; Kaiser & Schroeder, 2003; Lathan et al., 2002).

Questions such as this are part of the larger issue, recognized by Salas, Bowers, and Rhodenizer (1998), of the gap between technological advances in simulator capabilities and theoretical advances in training research. Salas et al. point out that to enhance the effectiveness of training, the focus should be not on designing technologically complex and realistic simulators but on designing them based on learning needs. Ward, Williams, and Hancock (2006) suggest that training has often been based on historical precedents or fashionable constructs with only limited empirical evidence in support of their utility. In line with that, virtual trainers for procedural skills acquisition can now include immersive 3-D vision, haptic feedback, and so on, without full evaluation of their contribution to transfer of training compared to simpler technology systems.

The current research addressed this issue using a LEGO® assembly task and comparing real-world training and two alternative virtual training methods: virtual-physical fidelity training, with a 3-D manipulation environment that allowed trainees to perform the steps virtually, and cognitive fidelity training, in which trainees verbally described each step based on a diagram. The results were compared to a control group, which received no training.

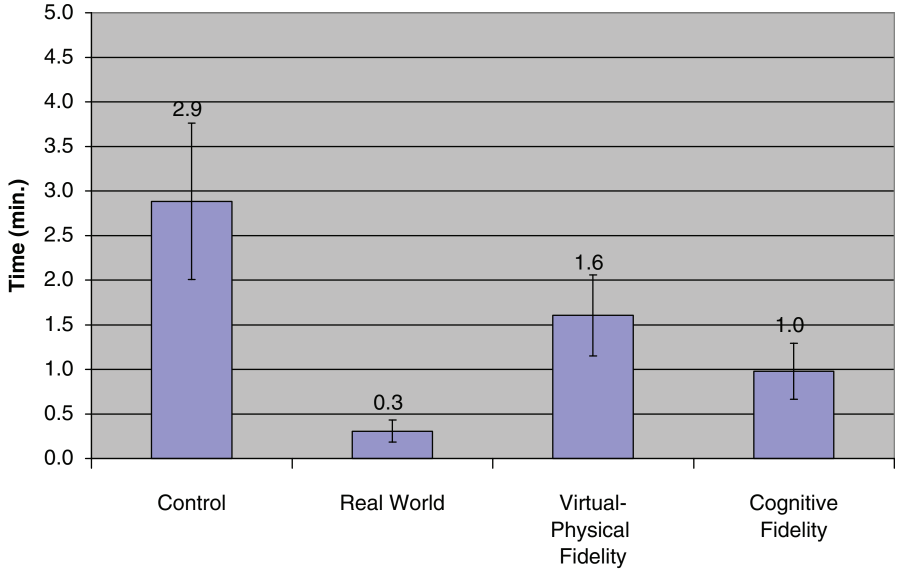

Figure 6. Mean time allocated to error correction and standard errors in the control, real-world, virtual-physical fidelity, and cognitive fidelity groups.

Overall, both the virtual-physical fidelity and cognitive fidelity training methods produced better performance time than no training at all, as did the real-world training. This finding thus confirms that both kinds of simulators can be useful for procedural skills training, especially at times when real-life training is impractical—for instance, when a device to be used is easily damaged, costly, or not always available, or when there is a possibility of risk to the person training for the task.

However, a closer look at the results shows that the two virtual trainers were not equal in their contribution to skill transfer. The cognitive fidelity group was inferior in terms of test time compared to the real-world training, whereas the virtual-physical fidelity group fell somewhere in the middle, with no significant difference either way. In contrast, only the real-world and the cognitive fidelity groups, and not the virtual-physical fidelity group, had an advantage over the control group in terms of time allocated to error correction.

This level of performance was achieved with a longer training time for the cognitive fidelity group as compared with both the real-world and virtual-physical fidelity groups. It should be noted, however, that the cognitive fidelity training method employed here was not designed to achieve optimal training. In a short informal interview during the debriefing, most participants in the cognitive group reported that the training was both tedious and tiring, and they felt that certain aspects of the training program—for instance, the requirement to name each brick—wasted time without contributing to improved performance.

Although the cognitive fidelity training was inferior to the real-world training in its performance time, the virtual-physical fidelity training group appeared to be at a disadvantage in terms of the time allocated to error correction. It may be that the problem for the virtual-physical fidelity group was that the virtual task was very similar to the real one, but not identical to it. The similarity may have led trainees to feel overconfident about their ability to construct the actual model. As a result, they worked too quickly. Similarly, the standard view of the U.S. Air Force is that platform motion is not recommended in flight simulators for centerline thrust aircraft (Cardullo, 1991) because for military planes performing large and fast maneuvers, the motion errors in moving base simulators differ considerably from those in actual flight—producing illusory conjunctions and, hence, negative transfer (Kaiser & Schroeder, 2003). In fixed-base simulators, the distinction between the simulator and the world is clear and unambiguous.

The current study's limitations derive from the use of the LEGO® task, which is a laboratory-based task that may not entirely reflect more realistic procedural tasks such as industrial maintenance. Our trainees' preexisting knowledge of LEGO® assembly was quite uniform. Individuals performing real-life procedural tasks are likely to have differing levels of prior experience, a fact that might influence the effectiveness of one or more training conditions.

Nonetheless, our results have important design implications. Specifically, our results suggest that the two approaches to virtual training have complementary advantages and that effective nonmotor training for the development of procedural skills in psychomotor tasks should incorporate both physical fidelity and cognitive fidelity training. For instance, trainees might start with cognitive fidelity training to help them memorize the order of the required steps, then move on to preparation incorporating greater physical fidelity to practice placing and fitting the components. Future research could develop such training protocols and test whether they enhance skill acquisition compared to the methods examined here.

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KEY POINTS

- The current study compared real-world training and two alternative virtual trainers, one emphasizing physical fidelity and the other cognitive fidelity of the task.
- Participants were randomly assigned to one of four training groups in a LEGO® assembly task: virtual-physical fidelity, cognitive fidelity, real world, and control.
- The cognitive fidelity training was inferior in terms of test time compared to the real-world training, whereas the virtual-physical fidelity training was not.
- Only the real-world and the cognitive fidelity groups, and not the virtual-physical fidelity group, required significantly less time than the control group for error correction.
- In conclusion, the two training methods have complementary advantages.

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