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Perceived learning outcome: the relationship between experience, realism, and situation awareness during simulator training

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ABSTRACT

Background. *Navigation errors are a frequent cause of serious accidents and work-related injuries among seafarers. The present study investigated the effects of experience, perceived realism, and situation awareness (SA) on the perceived learning outcome of simulator-based navigation training.*

Material and methods. *Thirty-two Norwegian Navy officer cadets were assigned to a low and a high mental workload conditions based on previous educational and navigational experience.*

Results. *In the low mental workload condition, experience (negatively associated), perceived realism, and subjective SA explained almost half of the total variance in perceived learning outcome. A hierarchical regression analysis showed that only subjective SA made a unique contribution to the learning outcome. In the high mental workload condition, perceived realism and subjective SA together explained almost half of the variance in perceived learning outcome. Furthermore, both perceived realism and subjective SA were shown to make an independent contribution to perceived learning outcomes.*

Conclusions. *The results of this study show that in order to enhance the learning outcomes from simulator training it is necessary to design training procedures and scenarios that enable students to achieve functional fidelity and to generate and maintain SA during training. This can further improve safety and reduce the risk of maritime disasters.*

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Key words: novice, expert, navigation, military

INTRODUCTION

Modern maritime operations require seamless interaction between crew and complex automated systems. Despite a number of technological improvements in navigation and bridge-based command and control systems, maritime accidents due to navigational failure and crew error still represent a risk to seafarers' health and safety. In order to improve safety and reduce the risk of fatal accidents, computer-based education and simulator training have become the methods of choice in maritime education. Simulator training is an excellent opportunity to acquire navigation skills, practise procedures, and to train situation awareness and decision-making. Training that results in greater maritime safety could be seen as a primary prevention strategy for maritime health. Although primary prevention is often thought of as involving the education of whole populations, specific training programmes for groups of individuals are also parts of primary prevention strategies [1]. Although simulator training has a number of advantages, it is a highly technology-driven learning tool

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where the educational outcomes of different forms of simulator training have been little explored. As a result, it is of vital interest to empirically test factors that increase the learning outcome of simulator training. The aim of the present study was to fill this gap in the literature by comparing perceived educational outcomes among novice and expert students exposed to two different training platforms.

Learning consists of acquiring knowledge, and personal knowledge is defined as “the cognitive resources which a person brings to a situation that enable them to think and perform” [2]. Students’ overall perception of learning has been used as an indicator of learning in educational research. In this article, perceived learning outcome is viewed as personal and thus subjective.

Maritime navigation involves complex, dynamic, and often cognitively demanding situations, which in turn can affect an operator’s performance. Several studies have indicated that situation awareness and decision-making are closely linked to performance [3, 4]. Situation awareness (SA) is defined as an individual’s perception, understanding, and projection of a complex environment. In 2006, our research group showed that brief specific SA training in a shoot/not-shoot simulator could improve police cadets’ SA in a critical situation [5]. The research group also studied individual differences in relation to SA, where low scores on Neuroticism and high scores on Extraversion and Conscientiousness (resilient personality type) predicted both subjective and observer SA in a navigation simulator [6]. These studies indicated that targeted simulator training could result in enhanced SA, thus linking individual differences and training effects.

Training studies have been performed in high-fidelity and low-fidelity simulators, so called technical fidelity [7, 8]. Unlike technical fidelity, simulator realism is related to functional fidelity, i.e. the extent to which the simulation is in accordance with the field of interest or with the real situation [9]. High simulator realism means that the participants experience the training as resembling real situations from their fields of interest. This is (likely) assumed to result in higher involvement and motivation. A high level of realism is also expected to positively affect transfer of training. If the participants do not see the training as being realistic, this could in turn affect their commitment to the training and the learning outcome.

Studies have reported a relationship between experience and SA, and, in particular, the ability to achieve and maintain SA. This ability seems to develop over time, resulting in an increased level of experience [10, 11]. As an example, novice pilots focus more of their attention on basic flying tasks than do experienced pilots who can carry out more tasks automatically [12]. In complex situations, novices’ limited attention and working memory capacity may affect SA, which can easily result in information overload due to task complexity exceeding a person’s limited attention capacity. This would be especially true of high workload situations. However, navigators also have to handle less mentally demanding situations, for instance during long transit voyages. Safe navigation and loss prevention will therefore require the ability to uphold SA and vigilance both in high and low workload situations.

Simulator training is used in order to improve safety and maritime health. The educational outcomes of such training have been little explored. The aim of the present study was therefore to investigate experience, perceived realism, and subjective SA in relation to perceived learning outcome during both low and high mental workload simulator training. Since experience is closely related to SA, it is necessary to control for experience when studying a possible unique relationship between SA and learning.

Based on reported differences between novices and experts relating to mental models, workload, and performance, a positive association between experience and perceived learning outcome was expected.

Furthermore, the intention was to see whether there was a relationship between perceived realism and perceived learning outcome. Based on reports stating that both high- and low-fidelity simulators can be used as training tools, a positive association was expected between perceived realism and learning.

SA can be trained in simulators, but most studies have used SA as an outcome variable. The present study therefore also studied the relationship between subjective SA and perceived learning outcome. More specifically, it examined whether subjective SA contributes more than the suggested effects of experience and perceived realism.

MATERIAL AND METHODS

SUBJECTS

Thirty-two naval cadets participated in this study. All of them had a minimum of 12 years of education. All 32 cadets had passed physical and psychological screening before starting at naval college. Based on their education level, all participants were divided into two groups.

The group of novices consisted of 16 cadets from the first year of training at the Royal Norwegian Navy Officer Candidate School. The mean age was 20.25 years (range: 19 to 25 years). The students had no prior experience of the use of navigation simulators. From their education they had acquired theoretical knowledge about navigation as well as taking part in practical "tabletop" exercises. They visited the Royal Norwegian Naval Academy as part of the basic course in simulator training and practical navigational training.

The other group (experts) consisted of 16 cadets from the second year of training at the Royal Norwegian Naval Academy. Their mean age was 24.25 years (range: 21 to 28 years). They had prior experience of the use of a radar simulator, optic simulator, and navigation simulator. They also had some practical experience of navigation during their education.

APPARATUS AND QUESTIONNAIRES

SA was measured using a self-report questionnaire "Situational Awareness Rating Scale" (SARS [13], adapted to naval operations; see also [5]). The Norwegian version consisted of 27 items (scored: 1 = "to a minor extent" to 6 = "to a great extent") with eight items measuring general abilities, 17 items measuring SA, and two additional items measuring the perceived realism and perceived learning outcome of simulator training.

The general ability items were excluded from the present study. An example of an SA-item was "To what extent were you able to create a plan for the navigation?". The perceived realism item was "To what extent did you perceive the simulator training as being realistic?" and the perceived learning outcome item was "To what extent did you learn from the training?".

Heart rate can be used as a measure of mental workload [6], and the cardiovascular responses were recorded using an Ambulatory Monitoring System (AMS) [14]. The cardiac responses were measured using 1cm Ag/AgCl ECG electrodes (Ultratrace, disposable pre-gelled electrodes). A standard three-electrode configuration was used as described by Mulder, Waard, & Brookhuis [15].

The data were collected during navigation training on two simulators at the Royal Norwegian Naval Academy. One simulator was 14 metres in diameter with a 360-degree horizontal visual field and a height of 3.40 metres. The other simulator had a 240-degree horizontal visual field. Both simulators were identically equipped as on a normal bridge on board a Norwegian naval vessel.

PROCEDURE

Before the start of the experiment, the participants read and signed an informed consent statement. They were informed about their right to leave the experiment at any time. No subjects withdrew from the experiment. They were also informed that their participation would have no effect on their future education or jobs.

At the beginning, all 32 cadets were briefed about the use of the two simulators and were given a short walkthrough of the routes. Two experts in navigation had estimated one easy and one difficult navigation task for both the novices and the experts. The two routes lasted for 75 minutes and 60 minutes, respectively.

Teams of four were randomly put together in the simulator. Each team consisted of a watch officer, chart, lookout, and helmsman. SA ratings were obtained from each team member after completing the task. This was done before the standard debriefing by the instructor. The experiment was semi-randomised based on each member's role in the team.

Two teams navigated at the same time in the two simulators. The use of the two simulators was balanced across the teams.

The self-rating of SARS produced two summary scores for the 17 SA-items: one for the low and the high workload scenario, as well as one score for each of the two items concerning perceived realism and perceived learning outcome.

Participants' cardiovascular responses were recorded continuously throughout the training session. First, baseline recordings were obtained while the subjects were seated for five minutes. Recordings were then obtained during the simulator training phases in which the subjects were engaged in navigation, and, finally, during a further five minutes of recovery while subjects were seated. Before analyses could be performed, artefacts in the recordings were corrected using an interpolation procedure [16].

DESIGN AND STATISTICS

A one-way analysis of variance (ANOVA) with repeated measurement was carried out in order to establish whether manipulation with low and high mental workload during navigation training worked as intended. A Fisher LSD-test was used as a post-hoc test. Pearson product-moment correlation was also used in order to examine the relationship between experience, perceived realism, subjective SA, and perceived learning outcome. To further assess this association, separate hierarchical multiple regression analyses were carried out using the enter method for both the low and high workload tasks. The first variable entered was experience. Then perceived realism was entered, controlling for experience, and, finally, subjective SA was entered, controlling for both experience and perceived realism.

RESULTS

MANIPULATION CHECK OF MENTAL WORKLOAD

A one-way analysis of variance was conducted to check for differences in mental workload during navigation training, and a main effect of workload was found, F (3, 84) = 10.75, $p < 0.01$. The post hoc test revealed an increase in heart rate from low workload training (M = 76.25, SD = 2.25) to high workload training (M = 79.44, SD = 2.09, $p < 0.05$). A recovery effect was found, with lower mean scores for recovery (M = 72.33, SD = 2.09, $p < 0.01$) than the scores for the low and high workload training. Recovery heart rate was also lower than the baseline level (M = 78.15, SD = 2.16, $p < 0.01$).

INTERCORRELATIONS BETWEEN EXPERIENCE, PERCEIVED REALISM, SUBJECTIVE SA, AND PERCEIVED LEARNING OUTCOME IN A LOW AND HIGH MENTAL WORKLOAD TASK

There was a significant negative relationship between experience and perceived learning outcome during the low mental workload task: r (32) = –0.48, $p < 0.01$. Furthermore, there was a positive significant relationship between perceived realism and perceived learning outcome: r (32) = 0.47, $p < 0.01$. Finally, there was also a positive significant relationship between subjective SA and perceived learning outcome: r (32) = 0.54, $p < 0.01$.

During high mental workload tasks, there was a significant relationship between perceived realism and perceived learning outcome: r (32) = 0.50, $p < 0.01$, as well as a relationship between subjective SA and perceive learning outcome: r (32) = 0.63, $p < 0.01$. There was no significant difference between experience and perceived learning outcome (see Table 1 for all intercorrelations).

REGRESSION ANALYSES OF PERCEIVED LEARNING OUTCOME DURING A LOW MENTAL WORKLOAD TASK

Hierarchical multiple regressions were used to assess whether experience, perceived realism, and subjective SA were related to perceived learning outcome. Experience was entered in Step 1. The result was a significant model explaining 23.5% of the variance in perceived learning outcome for a low mental workload task, F (1, 30) = 9.20, $p < 0.01$ (beta = –0.48, $p< 0.01$). In the second step, perceived realism was entered, and the total variance explained by the model was 29.6%. However, the model did not reach the significance level. In the third step, subjective SA was entered as the third variable after controlling for experience and perceived realism. The total variance explained by the model was 47.7%, F (3, 28) = 8.50, $p < 0.01$. Subjective SA for an easy task explained an additional 18% of the variance in perceived learning outcome, (R squared change = = 0.18, F change (1, 28) = 9.65, $p < 0.01$). In the final

Table 1. Correlations between experience, perceived realism, subjective SA, and perceived learning during low mental workload and high mental workload (n = 32)

Variables	Experience	Perceived realism	Subjective SA	Perceived learning outcome
Low				
Experience	–			
Perceived realism	-0.54**	–		
Subjective SA	-0.24	0.17	–	
Perceived learning outcome	-0.48**	0.47**	0.54**	–
High				
Experience	–			
Perceived realism	-0.58**	–		
Subjective SA	-0.41*	0.37*	–	
Perceived learning outcome	-0.28	0.50**	0.63**	–

**p < 0.01; *p < 0.05

model, the only significant variable was subjective SA (beta = 0.44, $p < 0.01$), see Table 2.

REGRESSION ANALYSES OF PERCEIVED LEARNING OUTCOME DURING A HIGH MENTAL WORKLOAD TASK

Identical statistical procedures were used as in the low mental workload task. Experience was entered in Step 1, resulting in a non-significant model. Perceived realism was entered in Step 2 after controlling for experience, and the model explained 24.8% of the variance in perceived learning outcome, F (2, 29) = 4.77, $p < 0.05$. Simulator realism explained an additional 17% of the variance in perceived learning outcome, (R squared change = 0.17, F change (1, 29) = 6.55, p < 0.05). Finally, controlling for experience and perceived realism, subjective SA was entered in Step 3, and the total variance explained by the model was 49.4%, F (3, 28) = 9.10, $p < 0.01$. Subjective SA for a high mental workload task explained an additional 24.6% of the variance in perceived learning outcome (R squared change = 0.25, F change (1, 28) = 13.60, $p < 0.01$). In the final model, the significant variables were perceived realism (beta = 0.39, $p < 0.05$) and subjective SA (beta = 0.55, $p < 0.01$), see Table 2.

DISCUSSION

The present study revealed that, during low mental workload training, experience, perceived realism, and subjective SA explained almost half of the total variance in perceived learning outcome. When entering the variables one by one, only subjective SA contributed positively to perceived learning. During high mental workload training, experience, perceived realism, and subjective SA combined explained approximately half of the variance in perceived learning outcome. Furthermore, both perceived realism and subjective SA made a unique contribution to learning.

There was a significant negative relationship between experience and perceived learning during low mental workload training. Experience was also the first variable entered in the regression model, explaining 23.5% of the variance in perceived learning outcome. This negative association indicates that lower levels of experience result in greater learning. Simulator training during low mental workload is less mentally challenging, and it could be argued that novices did not exceed their working memory capacity, with the result that novices were able to handle their navigational task, which, in turn, made them report higher perceived learning.

Low mental workload training should be even less cognitively demanding for experts. Greater experience enables the use of mental models and schemata of prototypical situations, which, in turn, results in high levels of situation understanding and good decisions, without taxing attention and working memory constraints [17]. The experts were expected to report a high learning outcome, but this was not the case. It could be argued that experts evaluate this training as too easy, which reduces their commitment and motivation.

The present study also reveals a significant negative relationship between experience and perceived realism. Thus, experts also reported less perceived realism than novices during low mental workload training. Experts do not view the training as being in accordance with real navigation practice, and they thus seem to experience a low level of functional fidelity. It could be argued that when training is not perceived as being realistic this will also have a negative effect on experts' perceived learning outcome.

This difference between experts and novices is also in line with Underwood, Chapman, Bowden, and Crundall [18], who reported experience-related differences in the ability to build mental models. Thus, the results from the present study seem to be in accordance with other results that have reported differences between experts and novices in terms of performance, training, and subjective SA [7, 19].

Table 2. Multiple Hierarchical Regression Analysis with experience, perceived realism, and subjective SA as Independent Variables, and perceived learning outcome as Dependent Variable during low and high mental workload training (n = 32)

	Perceived learning outcome Low workload			Perceived learning outcome High workload		
Variables	*B*	*SE B*	*β*	*B*	*SE B*	*β*
Experience	–0.79	0.55	–0.24	0.60	0.58	0.18
Perceived realism	0.32	0.20	0.27	0.47	0.20	0.39*
Subjective SA	0.06	0.02	0.44*	0.07	0.02	0.55**

**p < 0.01; *p < 0.05

During low mental workload training, there was a significant positive correlation between perceived realism and perceived learning outcome. This supports the hypothesis that high functional fidelity would positively affect perceived learning. Despite this, however, perceived realism did not explain perceived learning outcome after controlling for experience. Perceived realism only explained an additional 6.1% of the variance in perceived learning, and this result was not significant. This indicates that perceived realism shares much of the variance with experience.

The last variable entered in the regression was subjective SA. The correlation analysis showed a positive association between subjective SA and perceived learning outcome during low mental workload training. The regression models explained 47.7% of the variance in perceived learning outcome. After controlling for experience and perceived realism, subjective SA still explained 18% of the variance in perceived learning. Furthermore, only subjective SA contributed significantly to learning in this model. A high degree of subjective SA will result in a high degree of learning. One implication could be that SA is a necessary and sufficient factor in order to initiate learning during simulator training in low workload scenarios. Low intensity training is not intended to exceed the operator's cognitive capacity and create negative stress, but SA nonetheless seems to play an important role. High SA means good perception of information, comprehension, and ability to predict events in the near future during the navigation task. This can give rise to a positive experience, which, in turn, leads to the participants reporting a higher perceived learning outcome. Most studies on SA during simulation training have focused on high intensity situations. The present study extends previous knowledge by showing that SA is also the most potent factor in enhancing learning in low stress scenarios.

In contrast to the low mental workload training, the present study did not find a significant relationship between experience and learning during high mental workload training. This was not in accordance with our hypothesis. Once again, this could be caused by the experts not being committed or motivated during this type of training, even though heart rate measurements confirmed that the training did consist of two different training scenarios in terms of degree of mental workload.

In contrast to the low mental workload scenario, the high workload scenario showed that perceived realism explained 17% of the variance in perceived learning outcome. During cognitively demanding training, the participants reported perceived realism to be important in relation to perceived learning outcome. Because the situations were cognitively demanding, the participants used more of their mental resources in order to manage the navigation task. Since perceived realism is linked to functional fidelity, it helps the participants to manage the navigation and thereby provides support and enhances learning.

Subjective SA was the variable that explained most of the perceived learning outcome during low mental workload training. This result is further supported by the high mental workload training because, when controlling for experience and perceived realism, subjective SA still explains 24% of the variance in perceived learning outcome. The total model explained 49.4% of the variance in perceived learning outcome. These results support the importance of SA to learning using simulators, since SA explains most of the variance in both the low and the high workload training. If participants experience high subjective SA, this can promote decision-making and performance. Furthermore, it can help to reduce human errors, which is important in industries where safety is paramount. O'Brien and O'Hare [19] claim that successful performance in complex environments depends on factors like SA. Irrespective of training, participants with a higher underlying SA ability could perform dynamic complex tasks better than their lower SA counterparts. This study provides new evidence of the importance of designing simulator-based training that enhances SA, which, in turn, seems to facilitate learning. This has not been considered in previous research.

In 2005, Issenberg et al. [20] presented a review article that identified 10 features and uses for high-fidelity medical simulations that lead to effective learning. The features included the possibility of a controlled environment, feedback, clearly defined learning outcomes, and the fact that simulation permits individualised learning. Weller [21] reports that medical students set great store by simulation-based learning, and especially the opportunity to apply theoretical knowledge in a safe and realistic setting.

Taken together, the present study supports and extends some of the factors said to enhance effective learning. The results support taking the level of experience into consideration when designing simulator training. One implication is the need to tailor the scenarios used in training. Experts can experience simulator training as being too basic, resulting in low motivation and commitment to training. Secondly, effective training should not exceed the cognitive capacity of novices. However, it could be argued that the most important factor in generating learning using simulators is to construct scenarios that provide an opportunity to generate and maintain SA. Operators with high SA are more efficient at detecting critical signals, understanding the situation at hand, and projecting into the near future. These factors can be critical in relation to reducing human errors and preventing disasters at sea.

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