Forklift Driving Performance of Novices with Repeated VR-Based Training

Md Shafiqul Islam, Saman Jamshid Nezhad Zahabi, Sunwook Kim, Nathan Lau, Maury A. Nussbaum, Sol Lim

Department of Industrial and Systems Engineering, Virginia Tech, VA, USA

Abstract

Virtual reality (VR) has emerged as a promising tool for training novice forklift drivers, but temporal patterns of such improvements are largely unknown. We trained 19 novice participants using an order-picker VR simulator on a selected driving lesson. In two sessions, participant driving performance was assessed using task completion time and kinematics of the head, shoulder, and lumbar spine via inertial measurement units (IMUs). Completion time and head flexion/movement decreased significantly (up to 22.4% and 31.5%, respectively). The observed changes in head motion (flexion/extension) indicate an initial adjustment period to prepare a mental model of the driving task and the control panel, which was also adapted over repeated trials. One implication of our results is that reduced head flexion/extension could be used as an indication of a novice driver's improved skill during the early stages of training, in terms of familiarizing themselves with vehicle control and the vehicle control panel.

Keywords

Training and simulation, Virtual environments, Forklift

Forklift trucks are crucial in warehouse and distribution center operations (Vanheusden et al., 2020). Driving a forklift truck requires excellent hand-eye coordination and attention (Chande & Bandamwar, 2021), necessitating extensive training and practice. However, there is a national shortage of forklift drivers, posing operational challenges in various industries (Loske & Klumpp, 2021). Traditional training methods are limited by the need for a dedicated space and real forklift trucks (Herrera et al., 2018), which can lead to damage and accidents caused by inexperienced trainee drivers (Yuen et al., 2010). Virtual reality (VR)-based training is considered a cost-effective and space-saving alternative (Abbas et al., 2023; Villiers & Blignaut, 2016).

In this study, we evaluated the performance of novice drivers during repeated forklift training sessions using a VR-based simulator. We measured completion time and analyzed the kinematics of specific body parts. In this preliminary analysis, we explore the potential of kinematic metrics in assessing driving skills.cognitive workload. A secondary aim of the study was to investigate the effects of repeated training sessions on subjective and objective measurement of cognitive workload.

Nineteen participants (5 female, 14 male) with a mean (SD) age of 23.7 (5.1) years and valid driving licenses were included in this study. Two participants had less than one month of forklift driving experience, while the others had no experience. The study consisted of two sessions, scheduled within five days of each other. Each session involved a 10-minute training activity and two trials of a selected driving lesson. A high-fidelity VR-based forklift simulator (The Raymond Corporation, USA) was utilized for training, equipped with physical buttons and controls, a VR environment with various lessons, and a Vive Pro Eye headset with a Leap Motion controller. Upper body kinematics, including the head, torso, and left arm, were measured using five IMU sensors (MTw Awinda, Xsens, Netherlands). The Xsens system was calibrated for each participant before data collection.

Trial completion time was recorded by annotating the start and end times using Elan software (*v6.2*; Wittenburg et al., 2006). Start time was marked when participants secured their safety harnesses, and the end time was marked when they parked the vehicle in a designated area. IMU data were low-pass filtered using a second-order, zero-lag, Butterworth filter with a cut-off frequency of 5 Hz. Head rotation (axial), head flexion/extension, left shoulder rotation (internal/external), and lumbar rotation (axial) were calculated from the filtered IMU data. Standard deviations (SD) were used to measure motion variability, while peak (95th percentile) range of motion (ROM) represented movement magnitude in each trial.

Separate one-way, repeated measures analyses of variance (ANOVAs) were used to examine changes over the trials in each of the five dependent variables. Initial analyses with day as a blocking effect indicated no significant effects. Hence we proceeded with a reduced model. Bonferroni adjusted, paired-sample *t*-tests were used for *post-hoc* paired comparisons. Statistical analyses were performed using R *v4.1.1* (R Core Team, 2019), and significance was determined when $p < .05$.

Completion time significantly decreased across trials [$F(3,72) = 14.4$, $p < .001$]. Completion times decreased significantly between each trial: 1st–2nd ($p < .001$), 1st–3rd ($p < .001$), 1st–4th ($p < .001$), 2nd–4th ($p < .001$), and 3rd–4th ($p = .003$) trials. Completion times in 2nd and 3rd trials were not significantly different ($p = 1.0$).

Trial had a significant main effect on head flexion/extension SD but not peak ROM. Head flexion/extension variability was significantly lower in the 4th trial compared to the 1st [$t(1,18) = 4.32$, $p = .002$] and 3rd trials [$t(1,18) = 4.02$, $p = .005$]. SD and ROM values for head rotation, left shoulder rotation, and lumbar rotation were not significantly different between trials.

In this study, we investigated the performance of novice order-picker truck drivers in a virtual simulator during four trials and over two days while the same driving lesson. Repeated trials in the VR training resulted in a significant decrease in completion time, indicating improved performance. Faster task completion is associated with enhanced productivity in forklift operations (Sarupuri et al., 2016), a crucial aspect of warehouse functioning. However, our study design limited the determination of the specific training duration required to reach a performance plateau or expertise level. Further research is needed to establish the necessary training duration for novices to achieve a stable expertise level.

Motion variability in head flexion/extension changed across the trials. In the 4th trial, SD values were significantly lower compared to the 1st and 3rd trials, indicating reduced variability by 32% and 30%, respectively. While ROM did not show significant differences, the 4th trial exhibited lower ROM values (reductions of 46.1%, 38.7%, and 43.9% compared to the 1st, 2nd, and 3rd trials, respectively). This reduction suggests that as participants became more familiar with the lesson and environment, they required less head movement to observe their surroundings and the control panel. No significant differences were observed in head rotation, likely due to the task simplicity, which only required participants following a predefined path with turns. Using more complex tasks involving fork maneuvering or reverse driving may yield greater head rotation variability especially in the 1st trial. Additionally, there were no significant differences in the left shoulder or lumbar rotation, potentially due to the specific lesson requirements.

Our study focused on the basic maneuvering task of an order picker truck with novice participants, mainly college students. Therefore, the results may not be representative of the broader forklift driver population in terms of age, gender, and prior job experiences. Future research should consider including a more diverse sample. Additionally, investigating the transfer of learning to real driving environments is crucial to assess the effectiveness of VR training for novice drivers.

ACKNOWLEDGEMENT

This study was supported by The Raymond Corporation (a Toyota Industries Company) University Research Program. The authors are grateful to student research assistant Hsiang-Wen Hsing for providing technical support with the study.

REFERENCES

Abbas, A., Seo, J., Ahn, S., Luo, Y., Wyllie, M. J., Lee, G., & Billinghurst, M. (2023). How Immersive Virtual Reality Safety Training System Features Impact Learning Outcomes: An Experimental Study of Forklift Training. *Journal of Management in Engineering*, *39*(1), 04022068. https://doi. org/10.1061/(ASCE)ME.1943-5479.0001101

Chande, P. K., & Bandamwar, K. L. (2021). Visual Examination Standard for Forklift and Crane Operators: A Report for 66 Operators of a Factory in Mumbai. *Indian Journal of Occupational and Environmental Medicine*, *25*(2), 63–66. https://doi.org/10.4103/ijoem.IJOEM_54_19

Herrera, D. F., Bolívar Acosta, S., Quevedo, W. X., Balseca, J. A., & Andaluz, V. H. (2018). Training for Bus Bodywork in Virtual Reality Environments. In L. T. De Paolis & P. Bourdot (Eds.), *Augmented Reality, Virtual Reality, and Computer Graphics* (*Vol. 10850*, pp. 67–85). Springer International Publishing. https://doi.org/10.1007/978-3-319-95270-3_5

Loske, D., & Klumpp, M. (2021). Learning effects and mental fatigue of forklift operators in food retail logistics: An empirical analysis through the lens of behavioral operations management. *IFAC-PapersOnLine*, *54*(1), 19–24. https://doi. org/10.1016/j.ifacol.2021.08.071

Sarupuri, B., Lee, G. A., & Billinghurst, M. (2016). Using augmented reality to assist forklift operation. *Proceedings of the28th Australian Conference on Computer-Human Interaction*, 16–24. https://doi.org/10.1145/3010915.3010952

Vanheusden, S., van Gils, T., Caris, A., Ramaekers, K., & Braekers, K. (2020). Operational workload balancing in manual order picking. *Computers & Industrial Engineering*, *141*, 106269. https://doi.org/10.1016/j.cie.2020.106269

Villiers, P. D., & Blignaut, S. (2016). *Readiness of Forklift Operators to Train with Serious Games*. 1696–1704. https:// www.learntechlib.org/primary/p/173174/

Wittenburg, P., Brugman, H., Russel, A., Klassmann, A., & Sloetjes, H. (2006). *ELAN: A professional framework for multimodality research*. 1556–1559. https://pure.mpg.de/pubman/ faces/ViewItemOverviewPage.jsp?itemId=item_60436

Yuen, K. K., Choi, S. H., & Yang, X. B. (2010). A Full-immersive CAVE-based VR Simulation System of Forklift Truck Operations for Safety Training. *Computer-Aided Design and Applications*, *7*(2), 235–245. https://doi.org/10.3722/ cadaps.2010.235-245