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Effects of Proper Helmet Wearing on the Protection Performance for Industrial Helmets

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Abstract: Wearing an industrial helmet is recognized as one of the most important prevention strategies that can be employed on construction sites to reduce work-related traumatic brain injury. Chin strap and suspension adjustment mechanisms are two important components of a typical industrial helmet. However, not enough attention has been focused on standardized testing methods for evaluating these components of the helmet. International test standards do have some methods to test the strength of the chin strap, but they do not test the protective quality of a helmet with proper use of the chin strap and suspension adjustment systems. Fatal incidents at construction sites associated with helmet use are often not due to failure of the chin strap and suspension adjustment mechanisms, but because of the inappropriate use of these mechanisms. The purpose of this current study is to investigate the helmets' shock absorption performance when the chin strap and suspension adjustment mechanisms are properly used. Head impact tests were performed by letting a male, instrumented manikin free fall, from a standing posture, resulting in contact impacts of the head with two different surface materials (concrete and plywood). The current study indicates that properly wearing industrial helmets will play a role in the helmets' protection performance for some conditions.

***Keywords**:* Industrial helmet, Manikin, Head impact, Head impact criteria (HIC)

1. Introduction

Wearing an industrial helmet is recognized as one of the important prevention strategies that can be employed on construction sites to reduce work-related traumatic brain injury (Janicak 1998). Occupational Safety and Health Administration (OSHA) regulations for the construction industry require that employers shall ensure each employee wears a protective helmet when working in areas where there is a potential for injury to the head from falling objects (OSHA 2012). Although Type I helmets are designed mainly for the head protection against top impact, they are widely used in construction sites as all-purpose protection helmets. The fall protection performance of Type I helmets has not been evaluated. Chin strap and suspension adjustment mechanisms are two important components of a typical industrial helmet. However, not enough attention has been focused on standardized testing methods for evaluating these helmet components. International test standards do have some methods to test the strength of the chin strap for industrial helmets (ANSI 2014; BS 2012). In many motorcycle accidents, fatal incidents were often not due to failure of chin strap or suspension system, but because of the inappropriate use of these

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mechanisms (Freitas et al. 2018). In many standards there is no requirement to test the suspension adjustment mechanism. No helmet test standards for industrial helmets are focused on the evaluation of the protective performance of a helmet with proper use of the chin strap and suspension adjustment systems. The purpose of this study is to investigate the helmets' shock protection performance when the chin strap and suspension adjustment mechanisms are properly used.

2. Methods

Head impact tests were performed by using a 50th Percentile, instrumented manikin (50th Percentile Rescue Randy, mass = 66 kg, height = 1.65 m, GT Simulators, Davie, FL). We have modified the manikin with reinforced spine and shoulder elements and a Hybrid III neck (Model \#78051-90-H, Humanetics, Farmington Hills, MI). Acceleration of the head during impacts was measured at a sampling rate of 1000 Hz using a tri-axial accelerometer (Model #66F11, Endevco, Depew, NY) installed in the manikin's head. At the start of the test, the manikin was lifted to a height of 5 feet (1.5 m), as illustrated in Figure 1. The manikin was released by a magnetic mechanism to free fall which allowed the manikin's head back to impact with a concrete block. The impact surface was covered with different materials. There were four replicates for each of test conditions. The fall impact events were captured via a high-speed camera.

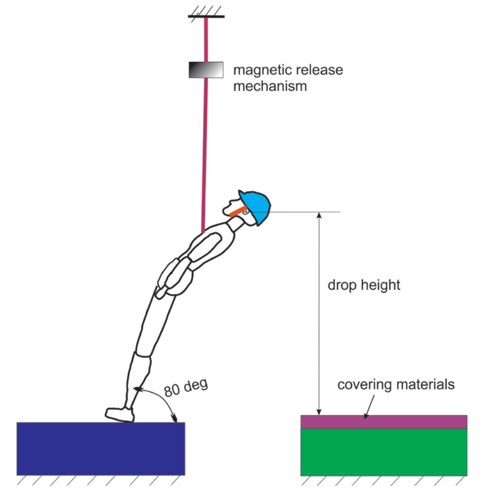

Figure 1. Schematics of experimental set-up for the manikin impact tests. Before the impact, the manikin was hoisted to a height of 1.5 m from the impact surface using a lifter.

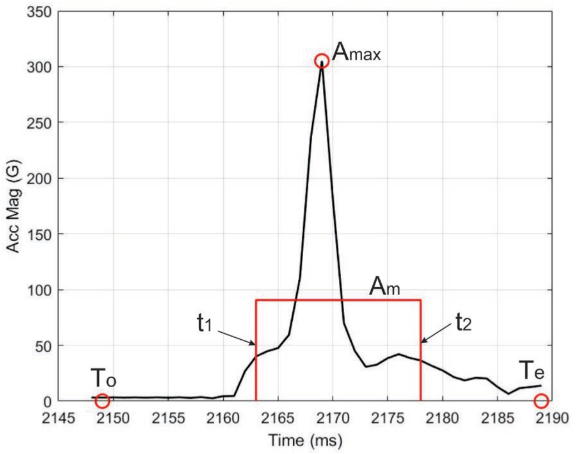

Figure 2. Illustration of HIC calculation. $A_{\max}$ is the peak acceleration magnitude. A_{m} is the average acceleration magnitude during the time interval (t_2-t_1 = *15 ms*).

A typical, basic industrial helmet model, which is categorized as a Type I helmet according to ANSI Z89.1 (ANSI 2014), was used in the current study. The Type I helmet is designed to protect from top impacts by a falling object. The impact tests were performed by using a fixed fall height (1.5 m); with or without wearing the chin strap; with three suspension tightness levels; and with two different impact surface conditions (plywood and concrete). There were four replications for each of the test conditions. This experimental design resulted in 48 impacts.

Using the head accelerations, head impact criteria (HIC$_{15}$) was calculated and used to evaluate potential injury risk from the impacts (Prasad et al. 2010):

$$\mathrm{HIC}_{15} = \max_{T_o \le t_1 < t_2 \le T_e} \left[\left(\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right)^{2.5} (t_2 - t_1) \right], \tag{1}$$

where *a(t)* is the acceleration magnitude in *G*; T_o and T_e is the start and end, respectively, of the computational time-period for the HIC; t_1 and t_2 is the initial and final instant of a time interval, respectively. For HIC$_{15}$, t_2-t_1 = 15 ms, the accelerations in three directions (a_x, a_y, a_z) were recorded in the tests. In the data procession, the calculations of HIC and peak acceleration (A_{max}) were based on the acceleration magnitude or the vector sum of the accelerations, i.e. $a(t) = \sqrt{a_x^2 + a_y^2 + a_z^2}$.

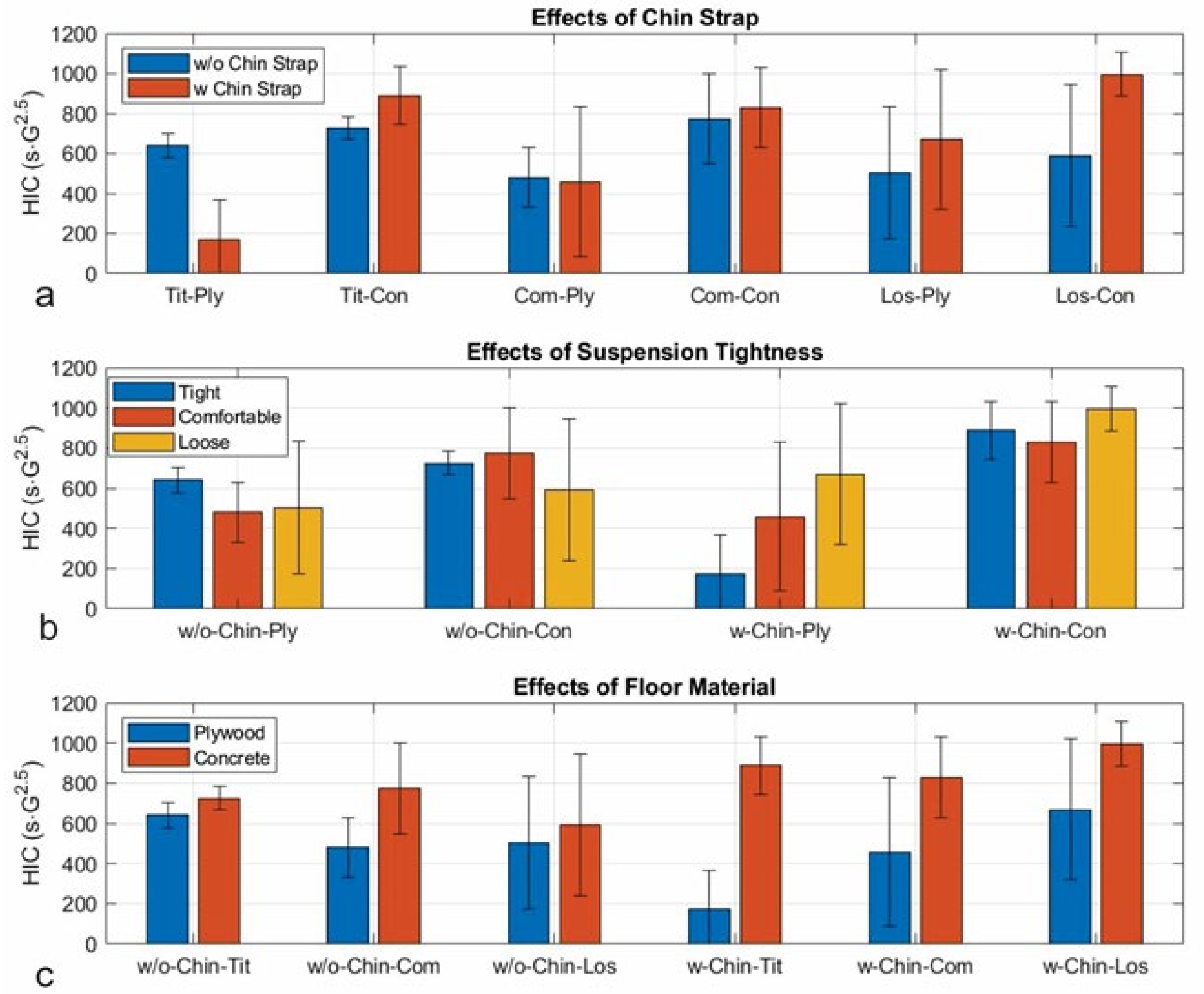

Figure 3. HIC_{15} of the manikin tested in different conditions. (a) Effects of the chin strap use. (b) Effects of the suspension tightness. (c) Effects of the impact surface materials. Tit-, Com- and Los- imply the impact tests with Tight, Comfortable, and Loose suspension, respectively. W/o-Chin and w-Chin imply the impact tests without and with chin strap, respectively. Ply and Con imply the impact surface covered with plywood and concrete, respectively.

3. Results

In all fall impacts, the helmets stayed on the manikin's head before and after the impacts. The manikin's head stroked on the impact surface on the back at an approximately same angle and location in each of the impact trials. Typical raw test data are illustrated in Figure 2. In data processing, the peak acceleration magnitude (A_{max}) was first determined, and then a time duration (T_o and T_e) around A_{max} was designated for the HIC_{15} calculation. The selection of an appropriate length for this time duration (T_o -T_e) would help reduce the computational time. In this study, $(T_o-T_e) = 3\ (t_2-t_1)$ was designated in the data processing. The selection of the computational interval length has no effects on the final values of HIC_{15}, as long as it covers well the range of (t_2-t_1). In our analysis, A_{max} was found to vary randomly and greatly even for the same test conditions (results not shown), whereas the mean acceleration A_m, which was used to determine HIC, was consistent. In addition, HIC was related to the injury risks (Hayes et al. 2007). Therefore, HIC was used to evaluate the effects of different test conditions on the helmets' protection performance.

The use of a chin strap helped to increase the protection performance (i.e., HIC decreases) only in the test condition "Tit-Ply" (Figure 3a), i.e., the test with tight suspension and a plywood-covered impact surface. In all other five test conditions, the use of a chin strap did not help increase the helmets' protection performance. The same phenomenon is demonstrated more clearly in the analysis of the effects of the suspension tightness (Figure 3b). The suspension tightness had inconsistent effects on the helmets' protection performance in all test conditions except for the test condition "w-Chin-Ply" (Figure 3b), i.e., test with chin strap and a plywood-covered impact surface. For all test combinations, impacts on the concrete surface resulted in much higher HIC values than the impacts on the plywood-covered surface (Figure 3c).

4. Discussion and Conclusion

In all impact tests, the lowest HIC_{15} value was approximately 54 for the impact condition "w-Chin-Tit" (Figure 3c) (using the chin strap and with tight suspension) and impact on the plywood-covered surface. The highest HIC_{15} was approximately 320 for the impact condition "w-Chin-Los" (Figure 3c) (using chin strap and with loose suspension) and impact on the concrete surface. The impact with a HIC_{15} value of 320 will result in a chance of 11% for a serious head injury (Hayes et al. 2007). An impact with a HIC_{15} value of 320 is much severe than those observed in automobile crash tests (Mueller et al. 2021). The average HIC_{15} value for typical frontal crashes with a speed of 64 km/h was about 163 and 205, respectively, for tests equipped with airbag and without airbag (Mueller et al. 2021).

Since the tests were set up manually, the impacts for the same testing condition were not strictly *repeated* but *replicated*. The factors associated with the experimental variations include the setup of the manikin's initial height and posture, the setup of the helmet's position on the manikin's head, and the adjustment of the helmet's suspension tightness. Despite all these factors, the variations of the A_{max} and HIC obtained in the current study were in reasonable ranges.

Our results showed that the effects of the use of a chin strap and tightness of the suspension system are different for various impact conditions. However, if the observed results were averaged for all test conditions, these two factors would have no measurable effects on the helmets' protection performance. Head impact on the concrete surface resulted in significantly higher head injury risk (i.e., higher HIC value) than head impact on the plywood covered surface. The current study indicates that proper wearing of an industrial helmet will play a role in the helmets' protection performance for some conditions.

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Disclaimer

Reference

ANSI (2014). "ANSI/ISEA Z89.1: American National Standard for Industrial Head Protection." American National Standards Institute, \url{http://www.ansi.org}, Washington, DC.

BS (2012). "EN 397:2012+A1: Industrial Safety Helmets." British Standards Institution, \url{http://www.bsigroup.com}, London, UK.

Freitas, C. A., Furtado, A. M., Petterle, R. R., Pimentel, S. K., and Carvalho, F. H. (2018). "Helmet retention system types as a risk factor to properly attach the chin strap." *Traffic Inj Prev*, 19(2), 173-178.

Hayes, W. C., Erickson, M. S., and Power, E. D. (2007). "Forensic injury biomechanics." *Annu Rev Biomed Eng*, 9, 55-86.

Janicak, C. A. (1998). "An examination of occupational fatalities involving impact-related head injuries in the construction industry." *J Occup Environ Med*, 40(4), 347-350.

Mueller, B., MacAlister, A., Nolan, J., and Zuby, D. (2021). "Comparison of HIC and BrIC head injury risk in IIHS frontal crash tests to real-world head injuries." *27th ESV Conference*, NHTSA, Yokohama, Japan.

OSHA (2012). "1926.100/1910.135: Safety and Health Regulations for Construction, Personal Protective and Life Saving Equipment". https://www.osha.gov. *Personal Protective and Life Saving Equipment*, Occupational Safety and Health Administration, https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10663.

Prasad, P., Mertz, H. J., Dalmotas, D. J., Augenstein, J. S., and Diggs, K. (2010). "Evaluation of the field relevance of several injury risk functions." *Stapp Car Crash J*, 54, 49-72.