The Negative Effect on Postural Ergonomics of Non-Sedentary Workplace Desks in Virtual Reality

Jessica Sehrt
Frankfurt University of Applied Sciences
Frankfurt am Main, Germany
jessica.sehrt@fb2.fra-uas.de

Henrico Putra Neumann
Frankfurt University of Applied Sciences
Frankfurt am Main, Germany
henrico.neumann@stud.fra-uas.de

Julian Niclas Wenzel
Frankfurt University of Applied Sciences
Frankfurt am Main, Germany
julian.wenzel@stud.fra-uas.de

Luca Kindermann
Frankfurt University of Applied Sciences
Frankfurt am Main, Germany
luca.kindermann@stud.fra-uas.de

Valentin Schwind
Frankfurt University of Applied Sciences
Frankfurt am Main, Germany
valentin.schwind@fb2.fra-uas.de

ABSTRACT

Virtual reality (VR) is gaining increasing importance in an increasing number of places in daily life, particularly when gaming or working. Moreover, immersive activities are often performed while standing at physical desks and current devices can even register the physical properties of a virtual workplace to match the virtual content with haptics in the real world in front of the user. However, little is known about the effects of VR on how users perceive and ergonomically adapt to workplace desks when wearing a head-mounted display (HMD). In this user study, we conducted an experiment with 19 participants to investigate the effects of non-sedentary VR on the postural risk level, workload, and preferred desk height. The results indicate that being in VR negatively influences objective and subjective measures of ergonomics and increases postural risk while the preferred desk height remained unaffected. We found evidence that wearing the HMD negatively affects the neck posture at non-sedentary workplace desks. We contribute with our findings and highlight the need for improving the field-of-view and weight of HMDs for lower postural risk levels at workplace desks in non-seated VR.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; *Haptic devices*; Empirical studies in HCI.

KEYWORDS

Ergonomics, height adjustable desk, virtual workplace, virtual reality, head-mounted displays

MuC '22, September 4–7, 2022, Darmstadt, Germany

ACM ISBN 978-1-4503-9690-5/22/09…$15.00
https://doi.org/10.1145/3543758.3547541

ACM Reference Format:
Jessica Sehrt, Henrico Putra Neumann, Julian Niclas Wenzel, Luca Kindermann, and Valentin Schwind. 2022. The Negative Effect on Postural Ergonomics of Non-Sedentary Workplace Desks in Virtual Reality. In *Mensch und Computer 2022 (MuC '22), September 4–7, 2022, Darmstadt, Germany*. ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3543758.3547541

1 INTRODUCTION AND BACKGROUND

Standing is a body posture often taken by workers or gamers when the surrounding area must to be comfortably reached with the arms or when the legs cannot comfortably be placed [7, 31]. While standing at workstations can have a small but statistically significant positive effect in terms of fasting blood glucose levels and the body mass index (BMI) [29], it also reduces the risk for real postural injuries such as tendinosis, tension neck syndrome, and back pain [14, 24, 33]. In addition to the health-related issues, personal preferences in workplace comfort likely led to an increasing spread of height-adjustable desks that also so allow standing in front of the workstation [10, 28].

Height-adjustable desks are not only used for ergonomic reasons, but also for various applications that need to alternate between standing and sitting. Particularly in virtual reality (VR), there is also an increasing number of applications that can only be used effectively while standing, especially when interaction require a larger space for tracking and to avoid collisions with the physical environment [3]. Thus, for spatial and embodied interaction as well as for consistent (full body) tracking in VR with head-mounted displays (HMDs) the ability to stand and adjust the table height can be crucial not only for improved ergonomics of workplaces, but also for the optimal usage of such systems.

Since using VR applications and tracking that often requires interaction that cannot be performed while seated, ergonomics of height-adjustable desks are particularly important for users who want to use such desks in VR. However, little is known about the ergonomics of VR combined with work desks while standing. Particularly, while considering the phenomenon of distance underestimation in VR with HMDs [2, 13, 21], it is also important to understand if there are differences in the preferred table height adjustments. As more and more users are likely to spend more and more time with immersive technologies, health issues as a result of bad ergonomics

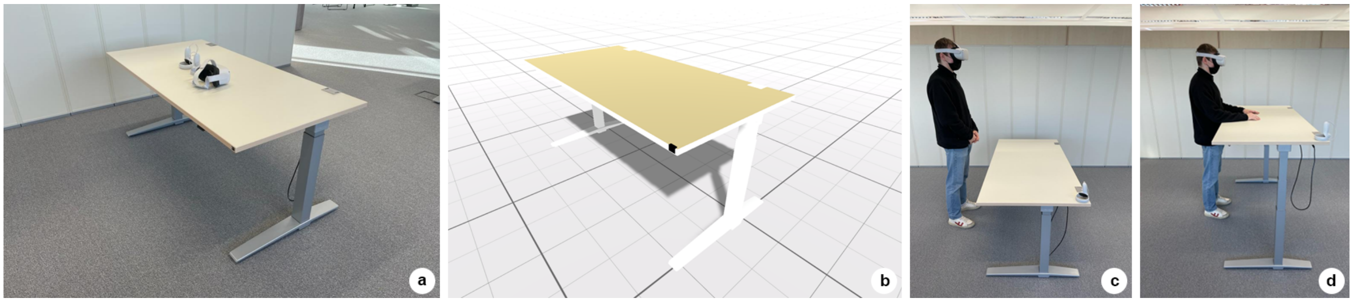

Figure 1: The real (a) and virtual (b) workplace desk conditions using a height-adjustable, physical desk. A virtual marker at the front, right corner of the table was used to visualize the height-adjusting button. The participants started from the minimal position of the desk (c) and were asked to adjust the table according to their preferred height. To ensure the participants were satisfied, they could rest their arms/hands on the table (d).

are particularly important for long-term use of such technologies and subject of ergonomics research.

The research in workplace ergonomics is not only focusing on how to design optimal workplaces but also utilizes VR technology to optimize and inform the user on ergonomic properties of their furniture. For example, while Whitman et al. generally highlights the external validity of VR for postural and ergonomic analysis [34], Mayer et al. use VR applications to support users in learning how to set up a work place ergonomically correct [19]. Similarly, to improve ergonomic awareness and postural feedback for personal desks, Lee et al. use real-time feedback in VR to adjust and design workstation configurations and designs [16]. Such information can be beneficial when training self-actuated furniture for automatic adjustments of personalized workplaces [17]. The advantage of such ergonomic workplaces is particularly evident in production and manufacturing industry where using VR technology is used for ergonomically optimized workplaces and can increase the efficiency and task completion time of workers on optimized workstations [27]. Moreover, Grajewski et al. [8] highlights that VR can provide virtual prototypes in professional working environments helping to build and evaluate prototypes without the risk of accidents while testing them. However, in comparing VR and real world workplace researchers repeatedly conclude that there are still some sensory and task-dependent differences mainly caused by lacking congruence between vision and haptics [4, 8, 26].

Both in real world as well in the virtual reality, designing workplaces ergonomically correct based on objectively assessments is crucial for workplace users. One well-established and validated tool is the Rapid Upper Limb Assessment (RULA) developed by Namwongsa et al. [20]. RULA can assess the ergonomic risk of upper body postures at workplaces while standing. Compared to other ergonomic assessment tools such as REBA [11] or the strain index [22], RULA seems to be the most effective as an measurement tool while assessing the postural risk of a person in non-sedentary settings [32]. Moreover, RULA can be used to assess ergonomic risk for tasks assembly plants or even for children's workplaces [5, 6]. The tool has also made a significant contribution to the ergonomic analysis of devices in human-computer interaction (HCI). For example, Namwongsa et al. investigated how the usage of mobile phones increases the user's postural ergonomic risk particularly due to bad neck postures [23]. Researchers are currently also working on the implementation of real-time analyzes based on the RULA score for the direct visualizing of the postural ergonomics with high development and system effort for posture correction and training [1, 18].

With increasing importance of embodied and spatial interactions in VR it is not only important to understand how users work or play in simulated environments, but also to understand how the postural ergonomics change due to co-located parts in the real and virtual world – such as physical workplace desks [15]. In this paper, we present the results of an experiment with 19 participants to investigate the effects of non-sedentary VR on the postural risk level, workload, and preferred desk height. We compared our measurements of users situated in the real and virtual world. We contribute with our findings that postural risk can be increased through wearing an HMD and highlight the need for improving the device ergonomics such as the field-of-view (FoV) specifications for lower postural risk levels at workplace desks in non-sedentary VR.

2 METHOD

To investigate the effects of wearing an HMD while being at a non-seated virtual workplace, we conducted an experimental user study with the Environment as the independent within-subject variable comprising the levels *real workplace* and *virtual workplace*. The factor implies the usage of an HMD with all its limitations and, thus, is maybe not solely responsible for the manipulation. Using a physical height-adjustable desk table, we measured the participants' body height, their preferred desk height, the ergonomic and postural influence on their body posture while standing, and their perceived workload. Postural ergonomics were determined using the RULA tool [20], which can only be determined while standing at workplaces. We measured the angles of the necessary body parts and determined the RULA sub-component scores (C, D) based on angles of the lower and upper arm, wrist, shoulder, neck, trunk and upper leg orientation [20]. The RULA score is based on postural angles, which have been measured using a digital goniometer to avoid any biases. Final scores were assessed according to the original procedure worksheet [20]. The participants' body size and the adjusted desk height were measured with a laser distance meter. Perceived

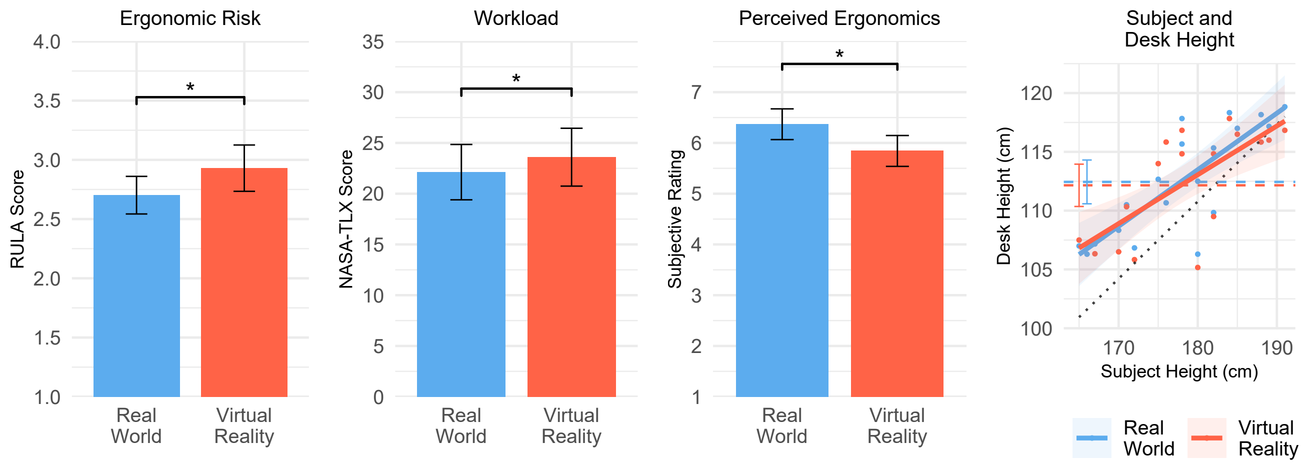

Figure 2: From left to right: Mean values of the RULA scores indicating the postural risk, the raw NASA-TLX, a custom item on subjective ergonomics (rated from 1-7), and the table height measured as a function of subject height (in cm) in the *real* as well as the *virtual* environment. RULA and NASA-TLX scores were in VR significantly higher. Subjective ergonomics was lower in VR. Linear regression (right plot) showed an effect of subject height, but no effect of the environment on table height. Dashed line indicates the overall means, dotted line show the recommended surface height for elbow placement [7]. All error bars show 95 % confidence interval.

workload of standing at the workplace was assessed using the raw NASA taskload index (NASA-TLX) [9] after each condition.

After providing informed consent, participants were introduced with the functionality of the height-adjustable desk (580 - 1230 mm) and the HMD – an Oculus Quest 2 operating as a stand-alone device and with 120Hz to prevent any motion sickness. The Oculus Quest 2 has an FoV of 104.0° (horizontal) and 98.0° (vertical). Moreover, the device has currently the highest precision (0.06 mm) in object tracking among off-the-shelf devices for room-scale VR [12]. Participants were surveyed for their demographics and if they had any experiences with desk adjustable desks, VR and if they suffer from any issues caused by bad body posture.

Before starting the experiment, the participants' height was measured. In the *virtual* condition, the participants took on the VR headset and were instructed as follows: "Adjust the preferred desk height in a way to feel most comfortable in". To make sure the participants were satisfied, they could rest their arms/hands on the table. We used the Oculus Quest 2 wireless controllers to track and display the virtual desk's height adjustments using a virtual replica of the desk in the Unity Game Engine. In the *real* condition, participants adjusted the desk without HMD. After the participants were satisfied with the height they had set through themselves, the angle measurements were taken by the experimenter. The procedure was repeated three times. Desk height was then set to the minimum level in order to ensure the same basis for the subsequent condition. After each condition, the participants were asked to remove their hands from the table, filled in the NASA-TLX questionnaire and three custom questions (1-7 point Likert item on how well the height adjustment worked, the perceived comfort, and ergonomics), and started with the next condition. The order of the conditions were counter-balanced for each participant to avoid any carry-over effects.

We recruited 19 participants (14 male, 5 female) via mailing lists of our institution. The mean age of the participants was 23.15 years ($SD = 1.80$) ranging from 20 to 27 years. Students were compensated with credit points for their participation. Eight participants stated to have any previous experience with VR devices, three of them owned an HMD. The average time of the participants spent at the desk a week while sitting was 22.73 hours and 2.42 hours while standing. Neck and back were the body parts for complaints, eight of them reported having no bodily issues at all.

3 RESULTS

3.1 RULA Score

The RULA score has been calculated according to original work [20]. An increased score indicates an increased postural ergonomic risk. Muscle and Force Load index of the RULA subcomponent remained constant according to the RULA posture table (Step 12-14) as no weight has been lifted. The average RULA score (see Figure 2) of the participants at the *real* workplace was $M = 2.702$, ($SD = 0.339$) and of the *virtual* one $M = 2.93$, ($SD = 0.492$). Shapiro-Wilk's normality tests indicated that the mean scores were normal distributed (*real*: $W = .912$, $p = .082$, *virtual*: $W = .942$, $p = .291$). A paired t-test revealed a statistically significant difference between both conditions, $t(18) = -2.233$, $p = .038$, $d = 0.503$ (medium effect size). Thus, the RULA score and associated postural risk was significantly higher in VR than in the real world.

The score consists of a number of individual angle measurements that are subsequently mapped based on a look-up table and calculated into a score. Individual sub-scale scores from the RULA tool

Table 1: Parameter estimates of the linear regression on the RULA score as outcome. Two coefficients (trunk and leg) could not defined because of singularities. Variance of each parameter contributes to the variance of the score. While the partial-eta square η^2 is associated with the partial variance of the predictors in percent, η^2_p and ϵ^2_p are unbiased estimators of the variance. Effect size estimates on the RULA score were highest for the neck assessments, which indicates that the neck mostly contributes to the (negative) RULA scoring.

Factor	Standardized β	$F(1, 33)$	p	η^2	η^2_p	ϵ^2_p	Cohen's f_p
Lower Arm	0.481	70.174	<.001	0.233	0.680	0.670	1.458
Upper Arm	0.149	29.701	<.001	0.098	0.473	0.457	0.948
Neck	**0.658**	**127.784**	**<.001**	**0.425**	**0.794**	**0.788**	**1.967**
Leg	0.962	39.419	<.001	0.131	0.544	0.530	1.092

are not foreseen from the original work for a deeper analysis, however, we were interested in which of the components contributed to the increased risk scores through the behavior of the participants without considering the environment as factor. Therefore, we performed a linear regression analysis using the RULA score as the dependent variable and the sub-scores as predictors. The regression equation was significant, $R^2 = .89$, $R^2_{Adj} = .876$, $F(4, 33) = 66.77$, $p < .001$. All parameter and effect size estimates can be found in Table 1. The results indicate that the sub-scores of the neck assessments showed the highest effect sizes. As no weights were lifted during the experiment, legs and trunk were consistently assessed by similar sub-scores. Thus, these findings cannot be generalized to other situations, but they indicate that neck negatively affected the RULA score in our experiment.

3.2 Raw NASA-TLX Score

The NASA-TLX score (see Figure 2) of the participants at the *real* workplace was $M = 22.123$, ($SD = 6.853$) and of the *virtual* one $M = 23.596$, ($SD = 7.163$). Shapiro-Wilk's normality tests indicated that the mean scores were normal distributed (*real*: $W = .965$, $p = .683$, *virtual*: $W = .967$, $p = .722$). A paired t-test revealed a statistically significant difference between both conditions, $t(18) = -2.455$, $p = .024$, $d = 0.208$ (small effect size). Thus, the TLX score was significantly higher in VR than in the real world.

We also looked into the individual NASA-TLX subscales. There was no significant difference between the ratings of mental effort, physical demand, temporal demand, and frustration (all with $p > .078$ and $d < 0.129$, with negligible effect sizes). Only the effort subscale showed significant effects, $Z = 0$, $p = .004$, $d = 0.472$ (small) between the ratings of the *real* workplace ($M = 1.842$, $SD = 0.781$) and the *virtual* one ($M = 2.386$, $SD = 1.193$).

3.3 Physical Workplace Desk Height

The subjects' average height was $M = 177.84\ cm$, ($SD = 7.85$). The average table height on the *real* workplace was $M = 112.44\ cm$, ($SD = 4.68$) and the average *virtual* table height $M = 112.15\ cm$, ($SD = 4.52$). The average relative difference between height of the participants and the *real* table was $M = 65.4\ cm$, ($SD = 4.93$) and the *virtual* one was $M = 65.69\ cm$, ($SD = 5.56$). A paired t-test could not reveal any statistically significant difference between the relative subject-table difference, $t(18) = -0.771$, $p = .450$, $d = 0.062$ (negligible effect size). A linear regression equation with table height as a function of body height and the environment was significant, $R^2 = .585$, $R^2_{Adj} = .561$, $F(2, 35) = 24.69$, $p < .001$. An general linear model could reveal a significant effect of body height, $F(1, 35) = 49.29$, $p < .001$, however, not of environment, $F(1, 35) = 0.09$, $p = .77$. The model indicates that body height is a good predictor ($\beta = .448$, $p < .001$) while the categorical environment does not significantly predict any variance of workplace desk height ($\beta = -.289$, $p = .768$). As the environment had no effect, we also determined the final regression equation ignoring the *real* and *virtual* space, $R^2 = .584$, $R^2_{Adj} = .572$, $F(1, 36) = 50.57$, $p < .001$, with $f(x) = 0.448x + 32.621$.

We also analyzed the absolute desk heights (see Figure 2). Wilcoxon signed rank test with continuity correction was performed on the absolute height of the desk as the assumption on normality has been violated (*real*: $W = 0.886$, $p = .027$, *virtual*: $W = 0.864$, $p = .011$) but the differences between the *real* ($M = 112.44$, $SD = 4.68$) and *virtual* ($M = 112.15$, $SD = 4.52$) workplace were not significant, $Z = 136.5$, $p = .099$, $d = 0.051$. Statistical power sample estimate to find a significant effect at 80 % is $N = 1990$.

3.4 Custom Questions

After each condition, we also asked participants three custom questions to subjectively assess the perceived easiness, comfort, and ergonomics of changing the desk height in the real and virtual workplace respectively. No control items were used. The items were analyzed using Wilcoxon signed rank tests. There was no effect on the item how *well* the participants could adjust the height in real ($M = 7$,$SD = 0$) or virtual ($M = 6.421$,$SD = 0.769$), $Z = 25.5$, $p < .305$, $d = 0.245$ (small effect size). However, we found a significant difference between the subjective perceived *comfort* of the *real* ($M = 6.474$, $SD = 0.841$) and *virtual* ($M = 6.263$, $SD = 0.872$) workplace, $Z = 36$, $p = .011$, $d = 1.065$ (large effect size). We also found a significant difference on the subjective assessment of perceived *ergonomics* (see Figure 2) between the *real* ($M = 6.368$, $SD = 0.765$) and *virtual* ($M = 5.842$, $SD = 0.765$) workplace desks, $Z = 64.5$, $p = .041$, $d = 0.689$ (medium effect size).

4 DISCUSSION

In this work, we investigated the effect of an VR HMD on the postural ergonomics on 19 participants while standing at a real and virtual workplace desk. As VR headset we used the Oculus Quest 2 with an FoV of 104.0° (horizontal) and 98.0° (vertical). The results indicate that wearing the HMD negatively influences the objective measures of the RULA score and subjective scales of workload (TLX) and the perceived ergonomics (custom questions). We found evidence that while using the HMD while standing, particularly the neck posture at workplace desks was negatively affected. Due to the limited FoV, we assume that the user is not able to see the complete surrounding without bowing and angling the neck into a less ergonomic position – leading to a worse ergonomic score. The questions of the workload are task-related and our task for the participants was to set the table until they stand comfortably. Thus, it can be assumed that the significant difference of the effort rating is related to both parts of the procedure (adjusting and standing comfortably). Based on the results we conclude that wearing an VR HMD increases postural risk due to bad neck postures, which are likely be caused by the limited FoV of the HMD - or even the HMD itself.

As wearing the HMD had no effect on the average table heights, we determined the general linear relationship directly between height of the participants and the preferred desk height with $f(x) = 0.448x + 32.621$. The equation can be used (and further refined) to predict the preferred desk height for workplaces that can be situated in the real as well as in a virtual world. We further contribute with the finding that the postural ergonomics for VR HMD must be improved in order to reduce the risk of suffering from postural damage during long-term use. This can happen by enlarging the FoV to match the natural human vision and/or by using noticeably lighter headsets to not adversely affect the neck. The limitations of the FoV can be tested, for example, by using a VR headset with a much larger FoV – for example the Pimax Vision 8k X offering an FoV of 200° [25], which approximately matches the human's angle of view.

Interestingly, there was no difference between the preferred physical desk heights in the real world and in VR. The finding that the table height does not change significantly can be explained by the procedure in which the participants have adjusted the table based on their body size just by using the haptic feedback when leaning towards the table and did rather not on the visual signal, which is interesting as previous work found that people rather underestimate distances in VR while using HMDs [2, 13, 21]. A study without visual feedback could support the assumption that haptics are in this case the more reliable cue (c.f. [30]). We particularly want to point out that our study is not able to differentiate between the effects of wearing an HMD and seeing the VR environment (e.g., with a limited FoV). Moreover, the drawn sample with a homogeneous group of students (no children, adolescents, or elderly) limits the generalizability of the results considering a wider population.

Thus, more research is needed to understand if the effect on bad postural (neck) ergonomics is rather caused by the weight (or the presence) an HMD, its limited FoV, or other factors such as weight or weight balance. It should also be noted that the risk can change due to the tasks that typically occur at a workplace (assembling, manufacturing, typing, writing, etc.) that should be considered by future work. The problem might be worse in AR when the FoV is even more limited. Another subject of future research could to present and design visual content in VR in a way that balances or rule out the postural risk in a positive way. This could finally help HMD manufacturers to reduce the postural risk of the users while wearing head-mounted devices.

REFERENCES

[1] 2003. *Integration of Immersive Environment and RULA for Real-Time Study of Workplace Related Musculoskeletal Disorders in the Upper Limb*. International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Vol. Volume 1: 23rd Computers and Information in Engineering Conference, Parts A and B. https://doi.org/10.1115/DETC2003/CIE-48298 arXiv:https://asmedigitalcollection.asme.org/IDETC-CIE/proceedings-pdf/IDETC-CIE2003/36991/1163/2592943/1163_1.pdf

[2] Ivelina V. Alexandrova, Paolina T. Teneva, Stephan de la Rosa, Uwe Kloos, Heinrich H. Bülthoff, and Betty J. Mohler. 2010. Egocentric Distance Judgments in a Large Screen Display Immersive Virtual Environment. In *Proceedings of the 7th Symposium on Applied Perception in Graphics and Visualization* (Los Angeles, California) *(APGV '10)*. Association for Computing Machinery, New York, NY, USA, 57–60. https://doi.org/10.1145/1836248.1836258

[3] Martin Bellgardt, Sebastian Pick, Daniel Zielasko, Tom Vierjahn, Benjamin Weyers, and Torsten W. Kuhlen. 2017. Utilizing immersive virtual reality in everydaywork. In *2017 IEEE 3rd Workshop on Everyday Virtual Reality (WEVR)*. 1–4. https://doi.org/10.1109/WEVR.2017.7957708

[4] Bernard R. Blais. 1999. Visual ergonomics of the office workplace. *Chemical Health & Safety* 6, 4 (1999), 31–38. https://doi.org/10.1016/S1074-9098(99)00013-1 arXiv:https://doi.org/10.1016/S1074-9098(99)00013-1

[5] Sara Dockrell, Eleanor O'Grady, Kathleen M. Bennett, Clare Mullarkey, Rachel Mc Connell, Rachel Ruddy, Seamus Twomey, and Colleen Flannery. 2012. An investigation of the reliability of Rapid Upper Limb Assessment (RULA) as a method of assessment of children's computing posture. *Applied ergonomics* 43 3 (2012), 632–6.

[6] Phillip Drinkaus, Richard Sesek, Donald Bloswick, Tom Bernard, Bob Walton, Brad Joseph, Gordon Reeve, and Joyce Counts. 2003. Comparison of Ergonomic Risk Assessment Outputs from Rapid Upper Limb Assessment and the Strain Index for Tasks in Automotive Assembly Plants. *Work (Reading, Mass.)* 21 (02 2003), 165–72.

[7] Claire Gordon, Thomas Churchill, Charles Clauser, Bruce Bradtmiller, John McConville, Ilse Tebbetts, and Robert Walker. 1989. Anthropometric Survey of U.S. Army Personnel: Summary Statistics, Interim Report for 1988. (01 1989).

[8] Damian Grajewski, Filip Górski, Przemysław Zawadzki, and Adam Hamrol. 2013. Application of Virtual Reality Techniques in Design of Ergonomic Manufacturing Workplaces. *Procedia Computer Science* 25 (2013), 289–301. https://doi.org/10.1016/j.procs.2013.11.035 2013 International Conference on Virtual and Augmented Reality in Education.

[9] Sandra G. Hart. 2006. Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50, 9 (Oct. 2006), 904–908. https://doi.org/10.1177/154193120605000909

[10] Alan Hedge and Earnest J. Ray. 2004. Effects of an Electronic Height-Adjustable Worksurface on Computer Worker Musculoskeletal Discomfort and Productivity. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 1 (Sept. 2004), 1740–. https://doi.org/10.1177/154193120404800803

[11] Sue Hignett and Lynn McAtamney. 2000. Rapid Entire Body Assessment (REBA). *Applied Ergonomics* 31, 2 (2000), 201–205. https://doi.org/10.1016/S0003-6870(99)00039-3

[12] Valentin Holzwarth, Joy Gisler, Christian Hirt, and Andreas Kunz. 2021. Comparing the Accuracy and Precision of SteamVR Tracking 2.0 and Oculus Quest 2 in a Room Scale Setup. In *2021 the 5th International Conference on Virtual and Augmented Reality Simulations* (Melbourne, VIC, Australia) *(ICVARS 2021)*. Association for Computing Machinery, New York, NY, USA, 42–46. https://doi.org/10.1145/3463914.3463921

[13] Fatima El Jamiy and Ronald Marsh. 2019. Distance Estimation In Virtual Reality And Augmented Reality: A Survey. In *2019 IEEE International Conference on Electro Information Technology (EIT)*. 063–068. https://doi.org/10.1109/EIT.2019.8834182

[14] Thomas Karakolis and Jack P. Callaghan. 2014. The impact of sit–stand office workstations on worker discomfort and productivity: A review. *Applied Ergonomics* 45, 3 (2014), 799–806. https://doi.org/10.1016/j.apergo.2013.10.001

[15] Pascal Knierim, Valentin Schwind, Anna Maria Feit, Florian Nieuwenhuizen, and Niels Henze. 2018. Physical Keyboards in Virtual Reality: Analysis of Typing Performance and Effects of Avatar Hands. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–9. https://doi.org/10.1145/3173574.3173919

[16] Bokyung Lee, Joongi Shin, Hyoshin Bae, and Daniel Saakes. 2018. Interactive and Situated Guidelines to Help Users Design a Personal Desk That Fits Their Bodies. (2018), 637–650. https://doi.org/10.1145/3196709.3196725

[17] Bokyung Lee, Sindy Wu, Maria Jose Reyes, and Daniel Saakes. 2019. The Effects of Interruption Timings on Autonomous Height-Adjustable Desks That Respond to Task Changes. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3290605.3300558

[18] Vito M. Manghisi, Alessandro Evangelista, and Antonio E. Uva. 2022. A Virtual Reality Approach for Assisting Sustainable Human-Centered Ergonomic Design:

The ErgoVR tool. *Procedia Computer Science* 200 (2022), 1338–1346. https://doi.org/10.1016/j.procs.2022.01.335 3rd International Conference on Industry 4.0 and Smart Manufacturing.

[19] Elisabeth Mayer, Klara Kriszun, Luisa Merz, Katja Radon, Marie Astrid Garrido, and Dieter August Kranzlmüller. 2021. Designing an Educational Virtual Reality Application to Learn Ergonomics in a Work Place. In *ACM International Conference on Interactive Media Experiences* (Virtual Event, USA) *(IMX '21)*. Association for Computing Machinery, New York, NY, USA, 247–252. https://doi.org/10.1145/3452918.3465504

[20] L Mcatamney and E Nigel Corlett. 1993. RULA: a survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics* 24, 2 (April 1993), 91–99. https://doi.org/10.1145/1188913.1188915

[21] Betty J Mohler, Sarah H Creem-Regehr, William B Thompson, and Heinrich H Bülthoff. 2010. The Effect of Viewing a Self-Avatar on Distance Judgments in an HMD-Based Virtual Environment. *Presence* 19, 3 (2010), 230–242. https://doi.org/10.1162/pres.19.3.230

[22] J Steven Moore and Gordon A Vos. 2004. The strain index. In *Handbook of Human Factors and Ergonomics Methods*. CRC Press, 109–114.

[23] Suwalee Namwongsa, Rungthip Puntumetakul, Manida Swangnetr Neubert, Sunisa Chaiklieng, and Rose Boucaut. 2018. Ergonomic risk assessment of smartphone users using the Rapid Upper Limb Assessment (RULA) tool. *PLOS ONE* 13, 8 (08 2018), 1–16. https://doi.org/10.1371/journal.pone.0203394

[24] Heather L. Nerhood and Steven W. Thompson. 1994. Adjustable Sit-Stand Workstations in the Office. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 38, 10 (1994), 668–672. https://doi.org/10.1177/154193129403801028 arXiv:https://doi.org/10.1177/154193129403801028

[25] LLC Pimax Technologies. 2022. *Pimax Vision 8K X*. Retrieved March 10, 2022 from https://pimax.com/product/vision-8k-x/

[26] Charles Pontonnier, Georges Dumont, Afshin Samani, Pascal Madeleine, and Marwan Badawi. 2012. Designing and evaluating a workstation in real and virtual environment: From digital mock-up to realization. In *2012 IEEE 3rd International Conference on Cognitive Infocommunications (CogInfoCom)*. 249–254. https://doi.org/10.1109/CogInfoCom.2012.6421988

[27] Zeeshan Qasim and Alireza Alipour. 2016. Application of a Virtual Reality and an Ergonomics Framework for Production Time Optimization: Case study in pen production. *Theses (Master's and Ph.D) – Mechanical Engineering* 1 (Jan. 2016). http://i-rep.emu.edu.tr:8080/jspui/handle/11129/4430

[28] Christopher Reiff, Kara L Marlatt, and Donald R. Dengel. 2012. Difference in caloric expenditure in sitting versus standing desks. *Journal of physical activity & health* 9 7 (2012), 1009–11.

[29] Farzane Saeidifard, Jose R. Medina-Inojosa, Marta Supervia, Thomas P. Olson, Virend K. Somers, Larry J. Prokop, Gorazd B. Stokin, and Francisco Lopez-Jimenez. 2020. The Effect of Replacing Sitting With Standing on Cardiovascular Risk Factors: A Systematic Review and Meta-analysis. *Mayo Clinic Proceedings: Innovations, Quality & Outcomes* 4, 6 (2020), 611–626. https://doi.org/10.1016/j.mayocpiqo.2020.07.017

[30] Valentin Schwind, Lorraine Lin, Massimiliano Di Luca, Sophie Jörg, and James Hillis. 2018. Touch with Foreign Hands: The Effect of Virtual Hand Appearance on Visual-Haptic Integration. In *Proceedings of the ACM Symposium on Applied Perception (SAP '18)* (2018-08-03). ACM, New York, NY. https://doi.org/10.1145/3225153.3225158

[31] Arijit Sengupta and Biman Das. 2000. Maximum reach envelope for the seated and standing male and female for industrial workstation design. *Ergonomics* 43 (09 2000), 1390–404. https://doi.org/10.1080/001401300421824

[32] Camille Shanahan, Peter Vi, Elizabeth Salas, Vanesa Reider, Lana Hochman, and Anne Moore. 2013. A comparison of RULA, REBA and Strain Index to four psychophysical scales in the assessment of non-fixed work. *Work (Reading, Mass.)* 45 (01 2013). https://doi.org/10.3233/WOR-121540

[33] Kazuki Takashima, Naohiro Aida, Hitomi Yokoyama, and Yoshifumi Kitamura. 2013. TransformTable: A Self-Actuated Shape-Changing Digital Table. In *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces* (St. Andrews, Scotland, United Kingdom) *(ITS '13)*. Association for Computing Machinery, New York, NY, USA, 179–188. https://doi.org/10.1145/2512349.2512818

[34] L.E. Whitman, M. Jorgensen, K. Hathiyari, and D. Malzahn. 2004. Virtual reality: its usefulness for ergonomic analysis. *Proceedings of the 2004 Winter Simulation Conference, 2004* 2 (Jan. 2004), 1740–. https://doi.org/10.1109/WSC.2004.1371525