

HUMAN TECHNOLOGY

Volume 17, Number 3, December 2021

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Human Technology, published by the Centre of Sociological Research, Poland, is distributed without a charge online.

Guest Editors' Introduction

WHEN TECHNOLOGY USE CAUSES STRESS: CHALLENGES FOR CONTEMPORARY RESEARCH

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INTRODUCTION

The current immense impact of ICT on individuals can be particularly strong in areas such as work and education. Both internet and computer systems have become an indispensable component of working or learning assignments. When ICT is missing, team cooperation and performance of certain tasks may be significantly limited. This has become especially clear recently, in the face of COVID-19 pandemic and all the challenges it has brought into our professional lives. Much of the workload had to be done virtually, forcing some employees and students to master new technologies enabling them to communicate through virtual platforms (e.g., Zoom or MS Teams) and to grasp the principles of digital and cyber safety at the same time.

Apart from the obvious benefits, the implementation of new technologies carries certain risks, which in the literature are described as 'iParadox' (Day, Barber, & Tonet, 2019). For example, on the one hand, ICT allows flexibility in exchange of the information between employees at any time of the day or night, but on the other hand, the employees feel obligated to check whether someone has sent message to them more often. Another example of iParadox is also the fact that technology helps co-workers or students and teachers keep in touch, especially in the case of distance working or learning, but at the same time it can be a source



of disruptive interferences and misunderstandings. Research shows that challenges related to the use of ICT constitute an independent source of stress together with other organizational stressors, such as lack of control, overload, boredom, and ambiguity (Day, Paquet, Scott, & Hambley, 2012) and contribute significantly to predictable negative consequences, e.g., professional burnout (Barber & Santuzzi, 2015). Moreover, virtual work during the pandemic and the high intensity and invasiveness of technology in our lives has resulted in heightened levels of techno-overload and conflicts between private and professional life (Molino et al., 2020).

Studies by work market analysts seem to indicate that organizations will not return to the former pre-crisis working solutions even after the pandemic subsides. The technological trend in ICT implementation which has recently emerged is here to stay (Savić, 2020). Virtual, computer-based technology enabled many institutions to revamp their processes and reduce costs (Thulin, Vilhelmson, & Johansson, 2019). The steep learning curve which employees had to rush along due to the pandemic will now have to be undertaken due to economic reasons. Therefore, increasing the awareness of how people react when learning new technologies becomes an imperative, as does the affect on performance of the consequences of such processes (technostress).

Although technostress is increasingly present in research, there is still a large gap to be filled. Moreover, analysis of the research findings on this subject reveals several crucial challenges. In the following sections, the selected research questions will address technostress and the challenges associated with it.

The Problem is Not Just about Employees

The available concepts and research results on technostress focus mainly on the organizational context. This phenomenon is well described from the perspective of employees and employers and quite well so in the group of professional teachers (Amarilla & Vargas, 2019; X. Wang & Li, 2019). However, there are very few theoretical studies and research results explaining how technostress affects the well-being and educational achievements of students. By definition, the use of new technology should support the effectiveness of learning and increase student achievements (Nami & Vaezi, 2018; Syvänen, Mäkinen, Syrjä, Heikkilä-Tammi, & Viteli, 2016). But is it really so? Moreover, it lacks reports on the relationship between attitude towards ICT and technostress among teachers and attitudes and technostress among students. Therefore, the question is how the way technology is perceived by teachers affects attitudes and technostress among students, especially in a situation when a new educational technology is introduced in a given class. It is also important to determine whether individual attitudes of teachers and students has an influence on the effectiveness of learning a new technology. Perhaps this problem has not been sufficiently exposed so far because students often have extensive knowledge of new technologies far in excess of the knowledge and skills of teachers. However, this does not mean that students' use of technology is not stressful.

Technostress Measurement Challenges

ICT properties which its users can experience such as overload, invasiveness and a compound effect of threat and uncertainty justify using those categories as the basis for some of the most popular technostress diagnostic tools (Ayyagari et al., 2011; Ragu-Nathan, Tarafdar, Ragu-Nathan, & Tu, 2008; Wang, Shu, & Tu, 2008). It is worth noting however, that items assessing technostress in these measures seem to be quite generic and refer to all IT technologies, instead of specific devices or applications. Therefore, there is a need for modified versions of these tools to diagnose perceived technostress in a more targeted way, and in reference to more specific technological solutions (e.g., smartphones, Facebook). Moreover, most current methods measuring technostress are self-assessment based (e.g. Gaudioso, Turel, & Galimberti, 2017; Ragu-Nathan et al., 2008; Salanova, Llorens, & Cifre, 2013).

Considering stressor-strain approach, it is possible to conclude that most studies of technostress are focused on stressors – stress inducing technology evaluation. There are very few studies addressing properties of technology which lead to objective stress reaction in its users. Riedl (2013) reviewed studies relating to autonomic and somatic nervous system response as well as endocrinological system response to individual's interactions with computer. He concludes that negative technology user's experiences result in heightened skin conductivity, raised blood pressure, heightened heart rate, and raised stress hormones levels (especially adrenaline and cortisol). Another significant effect he noticed was lowered melatonin levels, which can disadvantageously impact immunological system. The above mentioned reactions can result from one-off short-term problems, like shut down of a computer system (Riedl, Kindermann, Auinger, & Javor, 2012) or continuous overload connected with being involved in electronic mail system (Mark, Volda, & Cardello, 2012).

The approach rooted in diverse diagnostical methods can benefit the methodology of technostress research in multiple ways, e.g., considering both the psychological (self-assessment) and physiological (stress hormone secretion) technostress measures at the same time, helps to predict the task performance better than when each domain was studied separately. However, as it was evidenced by Fischer and Riedl (2017), despite their undeniable benefits, studies which use multiple measurements are extremely rare in technostress research.

A Multi-level Approach to the Analysis of Attitudes Towards ICT and Technostress

The majority of studies on the determinants of technostress conducted so far focused on individual factors, such as demographic variables, the sense of effectiveness in the field of ICT or personality traits (Shu, Tu, & Wang, 2011; Srivastava, Chandra, & Shirish, 2015; Tarafdar, Tu, Ragu-Nathan, & Ragu-Nathan, 2011). On the other hand, little research has been conducted to explain the role of organizational climate in explaining the phenomenon of technostress and the effectiveness of learning new technologies. A negative organizational climate has been shown to reduce psychological security among team members and ultimately to increase stressful situations (Finne, Christensen, & Knardahl, 2016). It should be expected that a similar mechanism occurs in the case of high incidence of techno-stressors in the learning environment. Research by Turel and Gaudioso (2018) shows that a positive leadership climate in the organization protects employees from perceiving technology as stressful, and a competitive climate intensifies the negative effects

of technostress. Ma and Turel (2019) proved that the level of technostress is related to organizational culture perceived by employees as power distance. However, so far, the issue of the climate of openness to ICT in the workplace or classroom and school has not been presented in a comprehensive manner. Furthermore, thus far the phenomenon of technostress has not been analyzed in a multi-level approach, i.e., the one in which technostress perceived by an individual results not only from individual differences, but also from being part of a given entity (team, organization, class, school).

According to the assumptions of concept of positive technology (Riva, Baños, Botella, Wiederhold, & Gaggioli, 2012), technology can perform three positive functions in human life: 1) hedonistic (technology is used to generate pleasant experiences); 2) eudaimonic (technology is supposed to support a person in achieving individual goals and self-realization); and 3) social (technology helps improve relationships with other people or groups). Promoting these three functions in an organization or school could help build a positive ICT climate, and thus support technology efficiency among its users.

Technostress Coping Strategies

The strength of the relationship between the perceived techno-stressors and stress response, as well as negative consequences, is determined to a large extent by more or less adaptive ways of dealing with technostress (Gaudioso et al., 2017). Beaudry and Pinsonneault (2005) investigated IT users coping strategies in reference to challenges arising from learning new computer technologies. Pirkkalainen and his team (Pirkkalainen, Salo, Makkonen, & Tarafdar, 2017) explored the efficacy of two main emotionally based coping strategies adopted in the IT environment. Their research points out that emotionally based coping strategies may to some extent mitigate tensions, but are not helpful in reducing technostress in the long run. Additionally, Gaudioso, Turel, & Galimberti (2017) demonstrated that the stronger the technological distress stemming from perception of ICT as overloading and invasive, the higher the propensity to employ maladaptive coping strategies. Some knowledge of technostress coping strategies does not go hand in hand with knowledge of the effectiveness of training and interventions to reduce technostress. Longitudinal studies are particularly lacking.

Complexity of Situational Factors

Both context and the course of new technology learning may significantly impact the perceived levels of technostress as well as the consequences of technology skills acquisition. One of the key characteristics of the job is computer-related technology dependence (Karr-Wisniewski & Lu, 2010), which is the extent to which employees have to depend on computer technology to carry out their tasks successfully. Shu, Tu and Wang's studies (2011) evidenced that employees whose dependence on computer-related technology was higher experienced higher levels of technostress. On the other hand, Weinert's and his team demonstrated that receiving instrumental support from help desks while experiencing difficulties in new technology learning process (computer freeze) effectively improves the level of task performance, lowers the user's physiological arousal and reduces burn-out resulting from technology use (Weinert, Maier, Laumer, & Weitzel, 2020). Moreover, the same study indicated that emotional support (compassion and comfort) in this stressful situation lowers only the physiological arousal, and does not affect the task performance

level, or long-term technostress consequences. Nevertheless, the above-mentioned studies are still rare. There are no complex research plans to illustrate the interaction of situational factors in shaping attitudes towards ICT and technostress.

Long-term Consequences of Technostress

Technostress researchers present strong evidence to corroborate the claim that stressors stemming from technology utilization (techno-stressors) impact employees in a meaningful way by evoking stress reaction, reducing their sense of well-being and self-efficacy (Ayyagari et al., 2011; Srivastava et al., 2015). Salanova and her team (Salanova et al., 2013) evidenced that a person's cognitive-emotional reaction to technology based negative experience entails anxiety, fatigue, skepticism, and a general self-efficacy drop in reference to utilizing ICT. Technostress is believed to reduce the ability to focus, the capability to form opinions, and to make the right decisions; it may also increase sense of ambiguity (Aghwotu & Owajeme, 2010). These symptoms are likely to affect one's capabilities to analyze situations or find solutions. In other words, technostress can significantly decrease levels of one's cognitive functioning, which in turn would reduce the technology-based task performance levels. However, explanation of the relationship between perceiving technology as stressful and the effectiveness of acquiring the skills to use it is a gap in scientific research that is yet to be filled. It remains unclear how perception of technologies impacts learning of new technologies. On the one hand, tension stemming from perceiving them as overloading, complex, invasive, uncertain, and threatening may lower the level of technological task performance. On the other hand, however, occurrence of stressors may motivate a person to find novel and creative ways to find new solutions for various efforts.

REFERENCES

- Aghwotu, P., & Owajeme, J. (2010). Technostress: Causes, symptoms and coping strategies among librarians in university libraries. *Educational Research*, 1(12), 713–720.
- Amarilla, S. B. G., & Vargas, S. F. P. (2019). Tecnoestrés docente: el lado opuesto de la utilización de las nuevas tecnologías por los Docentes del Nivel Medio. *Revista Científica Estudios e Investigaciones*, 8(1), 21–35. doi: 10.26885/rcei.8.1.21
- Ayyagari, R., Grover, V., & Purvis, R. (2011). Technostress: Technological antecedents and implications. *MIS Quarterly: Management Information Systems*, 35(4), 831–858. doi: 10.2307/41409963
- Barber, L. K., & Santuzzi, A. M. (2015). Please respond ASAP: Workplace telepressure and employee recovery. *Journal of Occupational Health Psychology*, 20(2), 172–189. doi: 10.1037/a0038278
- Beaudry, A., & Pinsonneault, A. (2005). Understanding user responses to information technology: A coping model of user adaptation. *MIS Quarterly: Management Information Systems*, 29(3), 493–524. doi:10.2307/25148693
- Day, A., Barber, L. K., & Tonet, J. (2019). Information Communication Technology and Employee Well-Being. In *The Cambridge Handbook of Technology and Employee Behavior* (pp. 580–607). doi:10.1017/9781108649636.022
- Day, A., Paquet, S., Scott, N., & Hambley, L. (2012). Perceived information and communication technology (ICT) demands on employee outcomes: The moderating effect of organizational ICT support. *Journal of Occupational Health Psychology*, 17, 473–491. doi: 10.1037/a0029837

- Finne, L. B., Christensen, J. O., & Knardahl, S. (2016). Psychological and social work factors as predictors of mental distress and positive affect: A prospective, Multilevel study. *PLoS ONE*, 11(3), 1–22. doi:10.1371/journal.pone.0152220
- Fischer, T., & Riedl, R. (2017). Technostress research: A nurturing ground for measurement pluralism? *Communications of the Association for Information Systems*, 40. doi: 10.17705/1cais.04017
- Gaudio, F., Turel, O., & Galimberti, C. (2017). The mediating roles of strain facets and coping strategies in translating techno-stressors into adverse job outcomes. *Computers in Human Behavior*, 69, 189–196. doi:10.1016/j.chb.2016.12.041
- Karr-Wisniewski, P., & Lu, Y. (2010). When more is too much: Operationalizing technology overload and exploring its impact on knowledge worker productivity. *Computers in Human Behavior*, 26(5), 1061–1072. doi: 10.1016/j.chb.2010.03.008
- Ma, Y., & Turel, O. (2019). Information technology use for work and technostress: effects of power distance and masculinity culture dimensions. *Cognition, Technology & Work*, 21(1), 145–157. doi: 10.1007/s10111-018-0503-1
- Mark, G. J., Volda, S., & Cardello, A. V. (2012). “A pace not dictated by electrons”: An empirical study of work without email. *The SIGCHI Conference on Human Factors in Computing Systems*, 555–564. doi:10.1145/2207676.2207754
- Molino, M., Ingusci, E., Signore, F., Manuti, A., Giancaspro, M. L., Russo, V., ... Cortese, C. G. (2020). Wellbeing costs of technology use during Covid-19 remote working: An investigation using the Italian translation of the technostress creators scale. *Sustainability*, 12(5911), 1–20. doi: 10.3390/SU12155911
- Nami, F., & Vaezi, S. (2018). How ready are our students for technology-enhanced learning? Students at a university of technology respond. *Journal of Computing in Higher Education*, 30(3), 510–529. <https://doi.org/10.1007/s12528-018-9181-5>
- Pirkkalainen, H., Salo, M., Makkonen, M., & Tarafdar, M. (2017). Coping with Technostress: When Emotional Responses Fail. *Thirty-eight International Conference on Information Systems*, 1–18. Seoul.
- Ragu-Nathan, T. S., Tarafdar, M., Ragu-Nathan, B. S., & Tu, Q. (2008). The consequences of technostress for end users in organizations: Conceptual development and validation. *Information Systems Research*, 19, 417–433. doi: 10.1287/isre.1070.0165
- Riedl, R. (2013). On the biology of technostress: Literature review and research agenda. *Data Base for Advances in Information Systems*, 44(1), 18–55. doi: 10.1145/2436239.2436242
- Riedl, R., Kindermann, H., Auinger, A., & Javor, A. (2012). Technostress from a neurobiological perspective: System breakdown increases the stress hormone cortisol in computer users. *Business and Information Systems Engineering*, 4, 61–69. doi: 10.1007/s12599-012-0207-7
- Riva, G., Baños, R. M., Botella, C., Wiederhold, B. K., & Gaggioli, A. (2012). Positive Technology: Using interactive technologies to promote positive functioning. *Cyberpsychology, Behavior, and Social Networking*, 15(2), 69–77. doi: 10.1089/cyber.2011.0139
- Salanova, M., Llorens, S., & Cifre, E. (2013). The dark side of technologies: Technostress among users of information and communication technologies. *International Journal of Psychology*, 48(3), 422–436. doi:10.1080/00207594.2012.680460
- Savić, D. (2020). COVID-19 and work from home: Digital transformation of the workforce. *Grey Journal*, 16, 101–104.
- Shu, Q., Tu, Q., & Wang, K. (2011). The impact of computer self-efficacy and technology dependence on computer-related technostress: A social cognitive theory perspective. *International Journal of Human-Computer Interaction*, 27, 923–939. doi: 10.1080/10447318.2011.555313
- Srivastava, S. C., Chandra, S., & Shirish, A. (2015). Technostress creators and job outcomes: Theorising the moderating influence of personality traits. *Information Systems Journal*, 25(4), 355–401. doi:10.1111/isj.12067

- Syvänen, A., Mäkinen, J.-P., Syrjä, S., Heikkilä-Tammi, K., & Viteli, J. (2016). When does the educational use of ICT become a source of technostress for Finnish teachers? *Seminar.Net*, 12(2), 95–109.
- Tarafdar, M., Tu, Q., Ragu-Nathan, B. S., & Ragu-Nathan, T. S. (2011). Crossing to the dark side: Examining creators, outcomes, and inhibitors of technostress. *Communications of the ACM*, 54, 113–120.
- Thulin, E., Vilhelmson, B., & Johansson, M. (2019). New telework, time pressure, and time use control in everyday life. *Sustainability*, 11(11), 1–17. doi: 10.3390/su11113067
- Turel, O., & Gaudioso, F. (2018). Techno-stressors, distress and strain: the roles of leadership and competitive climates. *Cognition, Technology & Work*, 20, 309–324. doi: 10.1007/s10111-018-0461-7
- Wang, K., Shu, Q., & Tu, Q. (2008). Technostress under different organizational environments: An empirical investigation. *Computers in Human Behavior*, 24(6), 3002–3013. doi: 10.1016/j.chb.2008.05.007
- Wang, X., & Li, B. (2019). Technostress among teachers in higher education: An investigation from multidimensional person-environment misfit. *Frontiers in Psychology*. doi: 10.3389/fpsyg.2019.01791
- Weinert, C., Maier, C., Laumer, S., & Weitzel, T. (2020). Technostress mitigation: an experimental study of social support during a computer freeze. *Journal of Business Economics*, 90, 1199–1249. doi: 10.1007/s11573-020-00986-y

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Human Technology
ISSN 1795-6889
<https://ht.csr-pub.eu>

PERCEIVED TECHNOSTRESS WHILE LEARNING A NEW MOBILE TECHNOLOGY: DO INDIVIDUAL DIFFERENCES AND THE WAY TECHNOLOGY IS PRESENTED MATTER?

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Abstract: *A growing body of research demonstrates that using technology can – despite the obvious benefits – be associated with stress. The aim of this study was to explore how perceived technostress while learning a new pro-healthy technology may be grounded in dispositional anxiety, attitudes towards ICT (Information and Communication Technologies), and the way technology is presented. Verifying the hypotheses, a study was conducted with the participation of $N = 1,037$ individuals, in which the 'technology presentation' was manipulated and selected individual differences were measured. As expected, it was found that presenting the new technology in the form of a popular science article was associated with the perception of this technology as more threatening and overloading compared to the situation in which the technology was presented in the form of a marketing leaflet with an unequivocally positive message. Moreover, it was shown that people characterized by higher dispositional anxiety perceived the new technology as more stressful in terms of examined categories of techno-stressors. Support was also found for the hypothesis that attitudes towards ICT correlate to selected dimensions of perceived technostress in regard to newly learned technology. However, the small extents of the effect obtained in the study indicated the need to continue searching for substantial factors that would predict technostress at the early stages of learning a new technology.*

Keywords: *technostress, dispositional anxiety, attitudes towards ICT, mobile technology.*



INTRODUCTION

Scientists have identified the technostress phenomenon as an adaptive challenge. Technostress seen from that angle stems from one's inability to seamlessly adapt to the demands of implementation or operation of new technology processes. This can be ascribed to one's wrestling with cognitive and social challenges of handling new technologies (Brod, 1982; Shu, Tu, & Wang, 2011; Tarafdar, Tu, Ragu-Nathan, & Ragu-Nathan, 2007). Although, it may seem that the exacerbated intensity of technostress may stem from more generic beliefs about one's computer skills (Shu, et al., 2011), or the role of computers in society (Beckers & Schmidt, 2001), the most indicative source of technostress is one's negative experience derived from either learning or utilising some specific technological solutions. In this case, learning new technology may be perceived as requiring a lot of effort or even threatening, and as such, quite an overwhelming experience (Day et al., 2019). Information communication technologies become a source of stress because they are complex, require fast and intensive learning (techno-complexity), effortful, ever-changing, force one to multitask (techno-overload), they abound in technical glitches and faults, they may be a source of excessive control or negative treatment (techno-threat), (for techno-creators overview see Ayyagari, Grover, & Purvis, 2011; Fischer, Pehböck, & Riedl, 2019; Tarafdar et al., 2007).

Most research on technostress focuses attention on the conditions, symptoms and consequences of this phenomenon in the workplace (Ayyagari et al., 2011; Ragu-Nathan, Tarafdar, Ragu-Nathan, & Tu, 2008). In the occupational context, the main driver of technostress is the pressure caused by the fear of not meeting expectations and not keeping up with new technologies, which increasingly determine professional effectiveness. However, technostress can be experienced in everyday life (La Torre, Esposito, Sciarra, & Chiappetta, 2019). Concerns about the use of new technologies may accompany learning the telephone, computer or software used in non-work areas. However, to the best of the authors knowledge, research on technostress in everyday life is still rare, especially in the context of the first experiences with new technology. The current study fills the gap in this regard, considering perceived technostress-creators while learning a new mobile application. This study also contributes to the simultaneous consideration of individual and situational variables in predicting perceived technostress.

The main aim of this research is to explore how dispositional anxiety, attitudes towards ICT, and the way technology is presented affects perceived technostress while learning new health mobile app. It is to explicate and test the role of psychological and contextual factors in the perceived technology as stressful in non-work context. The intended aim of the research was achieved through a study, where the presentation of a previously unknown health application was manipulated, while demographic and individual variables were controlled.

Individual Differences and Perceived Technostress

The presumption that people would evaluate the same technology use experience in the same way is quite limiting and biased. According to Lazarus and Folkman's Transactional Model of Stress (1987), different people will perceive the utilization of the same device or application as challenging, threatening, or quite neutral for their wellbeing. Moreover, even if a person's evaluates particular ICT experience as threatening, their emotional reaction will be dependent

on how they estimate their own coping potential in this context. Multiple studies evidence that individual differences shape people's technostress experience (for overview see Maier, Laumer, Wirth, & Weitzel, 2019). Research by Lee and colleagues suggests that technostress associated with excessive smartphone use is positively related to individual differences such as external locus of control, social anxiety, materialism, and the need for touch (Lee, Chang, Lin, & Cheng, 2014). Individual differences, and especially personality traits, may also moderate the relationship between the presence of techno-stressors in the workplace and the job performance. Despite the fact that perceiving technology as stressful is generally associated with negative work outcomes, in the case of people who are highly open-to-experience and extroverted, the presence of techno-stressors may be conducive to achieving positive work results (Srivastava, Chandra, & Shirish, 2015). Previous reports indicate that the personality trait of neuroticism is one of the key predictors of perceived technostress. Individuals high in neuroticism perceive technological advances as threatening and stressful to their daily functioning (Devaraj, Easley, & Crant, 2008; Krishnan, 2017). A particularly useful facet of neuroticism for explaining susceptibility to technostress is dispositional anxiety, understood as individual differences in the tendency to experience an emotion characterized by feelings of pressure, worried thoughts and physical changes like increased blood pressure (see Costa & McCrae, 1992). Dispositional anxiety can play a strong role in shaping cognitive processes associated with human-technology interaction. Anxiety signals the presence of potential threat and promotes responses that help individuals reduce their vulnerability to threat (Barlow, 1988), therefore we hypothesize that individuals high in dispositional anxiety would be more likely to perceive new technology as stressful (*hypothesis 1*). Next reason to expect that anxiety is associated with perceived technostress is that anxiety promotes pessimistic appraisals of future events (Shepperd, Grace, Cole, & Klein, 2005) - anxious individuals typically anticipate high levels of distress in response to an event threatening wellbeing or requiring adaptation.

A distinct category of protective resources shielding a person from technostress, is a set of beliefs one has about IT technologies, including self-efficacy in ICT implementation (Shu et al., 2011), as well as generic beliefs about the role of computers in human life and society (Beckers & Schmidt, 2001). These beliefs, as key components of ICT attitude, directly correspond with one's assumptions about technology experiences. Positive attitude towards ICT and high self-belief in regard to one's practical abilities may on one hand diminish threat reaction to it, and on the other, prompt adaptive coping strategies to handle new challenges better. Thus, we hypothesize that individuals manifesting more positive attitude towards ICT would be more likely to perceive the new technology as less stressful (*hypothesis 2*).

The Way New Technology Is Presented and Perceived Technostress

Although a lot of research has been conducted on the psychological, social and occupational effects of technostress (for systematic reviews see Borle, Reichel, Niebuhr, & Voelter-Mahlknecht, 2021; La Torre, Esposito, Sciarra, & Chiappetta, 2019), research on relationship between the way a new technology is presented and perceived stress-creators regarding this technology is limited. However, it can be expected that the form of the first experience with the new technology may be important in assessing the technology in terms of potential threat, overload or complexity.

When a new technology is introduced into use, information about its basic functionalities begins to reach potential users. This information may be provided, inter alia, in writing, e.g., in the form of a brochure, short instruction or reports in the form of a popular science article. The information presentation format, not only content of the message, shapes the first impression of the recipient on the presented information (Kelton, Pennington, & Tuttle, 2010). Information presentation format regards to the layout of the content (e.g., section breakdown), graphics, and also the language. It is well known that the language of science can be exclusive, which may be one of the obstacles to achieving one's scientific literacy (Laugksch, 2000).

One of the main categories of material evaluation is its complexity, which in the case of information on a new technology may be particularly important for shaping the first reaction. Techno-complexity is believed to be one of the main sources of stress regarding first experiences with new technology. Techno-complexity implies the amount of time and cognitive (intellectual) effort exerted by an individual in order to understand and master new technologies indispensable to perform work tasks successfully (Tarafdar et al., 2007). Techno-complexity manifests itself by the extent to which technology application instructions are complicated, the multiplicity of its functionalities is high and concepts describing workings of this technology are inaccessible. Whether one evaluates the new technology as cognitively demanding depends on a large extent of its specific properties but can also be attributed to the fact how this technology is being presented. Providing broad access to all the possible information about the technology can highlight its complexity and thus increase technostress. In order to reduce the perceived complexity of technology, it is advisable to present it in stages and to simplify the information about how this technology operates. Additional aspect which may lower the perceived complexity is the way of presenting the same information through more attractive way using graphs, more accessible language, etc.

Also, the sense of threat posed by new technology may be caused by the way the technology is presented. On the one hand, it may be a consequence of difficulties in understanding the fundamental aspects of technology and thus people perceive it as invasive, insecure or overly controlling. On the other hand, it may result from anticipating changes in the immediate environment due to technological development (general attitude towards ICT). The threat posed by new technology also results from the sense of insecurity a person faces when he or she suspects that others may know more about new technologies than he or she does (Tarafdar et al., 2007). As a result, people who perceive technology as threatening perceive it as a risk of undesirable changes in their lives (e.g., having to give up the current lifestyle, being excluded from social groups or rejected by an important person). Negative connotations with a new technology may intensify in the case of receiving complex or incomprehensible information about this technology, and weaken if this message is more interesting and easier to assimilate.

Following the above, we expect that individuals who are presented with key, brief chunks of information about this technology in the form of a leaflet (condition B) or a graphic simplified instruction (condition C) will perceive this technology as less complex (*hypothesis 3*) and less threatening (*hypothesis 4*) in comparison to individuals who will receive an excerpt from the scientific text about this technology (condition A).

METHODS

Participants

A total of $N = 1,037$ adults (including 741 women, 71% and 296 men, 29%) of the 1200 who were initially contacted (response rate of 86%) participated in the study randomly assigned to one of the three experimental conditions. The age of the respondents ranged from 18 to 78 years ($M = 25.48$, $SD = 11.05$). Most of the respondents had secondary education ($n = 665$; 64%), while the remaining persons had undergraduate ($n = 91$; 9%), graduate ($n = 155$; 15%), vocational or elementary education ($n = 126$; 12%). More than half of the respondents still attended high school or university ($n = 551$; 53%), the other persons were employed ($n = 243$; 23%), were employed and continued their education at the same time ($n = 194$; 19%) or did not work nor continued education ($n = 49$; 5%). The description of the study sample, broken down into three experimental conditions, is presented in Table 1.

Table 1. Sample Composition across Three Experimental Conditions.

Variable	Experimental condition A ($n = 323$)	Experimental condition B ($n = 369$)	Experimental condition C ($n = 345$)
Sex			
Female	232 (72%)	281 (76%)	228 (66%)
Male	91 (28%)	88 (24%)	117 (34%)
Age	$M = 25.19$; $SD = 10.80$	$M = 25.83$; $SD = 11.52$	$M = 25.39$; $SD = 10.79$
Education			
vocational or primary	44 (14%)	47 (13%)	35 (10%)
secondary	206 (64%)	239 (65%)	220 (64%)
undergraduate or graduate	73 (22%)	83 (22%)	90 (25%)
Educational/Professional status			
student	170 (53%)	205 (56%)	176 (51%)
employee	73 (23%)	88 (24%)	82 (24%)
learning and working	65 (20%)	59 (16%)	70 (20%)
leisured	15 (4%)	17 (4%)	17 (5%)

Note. Total sample $N = 1,037$.

Procedure

The study was conducted via an internet platform. Participants received a link to the survey by e-mail. After clicking on the link, each respondent was asked to answer demographic questions and complete a set of questionnaires measuring attitudes towards ICT and personality traits (see *Measures* section). In the next step, the subjects were randomly assigned to one of the three experimental conditions. In condition A participants were asked to read a short popular science article about the new health mobile application 'Felicit'. In condition B participants read a marketing flyer about the same application, and in condition C, participants were given to read an excerpt from the instructions on how to use the same health app, as in previous conditions. In particular

conditions, the content of the information was of the same volume, with a similar amount of text (about 1 page). The descriptions also contained all the key information about the application, they only differed in form (see *Appendix A*). Then, each participant, regardless of the condition, took a knowledge test measuring the level of knowledge of 'Felicita', and then answered the questions of the questionnaire measuring technostress related to this application (see Measures section). The study was conducted as part of a broader research project approved by the Ethics Committee of the Institute of Psychology at the University of Gdańsk (No. 9/2021).

Measures

A new measure of perceived technostress related to learning a new health technology was developed, describing major stress-creating conditions already identified in previous research. We used an item set inspired by the Technostress Creators Inventory (TCI) developed by Ragu-Nathan et al. (2008) and its adaptation to mobile technologies (Westermann, 2017). The original scales conceptualize technostress as being manifested in the five dimensions: techno-overload (too much), techno-invasion (always connected), techno-complexity (difficult), techno-insecurity (uncomfortable), and techno-uncertainty (too often and unfamiliar), (Tarafdar et al., 2011, p. 117). However, for the purposes of adjusting the measure of given new health mobile technology (not technology at all), we chose 14 fitting items, the wording of which was additionally modified. In developing the new scale, we focused on three categories of techno-stressors: overload (e.g., 'This technology would make my life even more complex and challenging'), complexity (e.g., 'It would take me a long time to learn this technology'), and threat as mix factors being a source of negative consequences for everyday life (e.g., 'This technology would be violating my personal life'). Respondents answered using a Likert scale from 1 to 5 (1 = strongly disagree, 5 = strongly agree). The results of the validation study using the modified tool supported three-factor structure are in press (for more details see Olech & Jurek, 2022).

The Attitudes towards Information Communication Technologies Scale (AS-ICT) was used to assess participants' attitudes towards technologies. It is a scale that consists of 23 items measuring 4 dimensions of attitudes towards ICT, i.e.: ICT utility (e.g., 'Using new information communication technologies improves quality of life', 'Without information communication technologies, there would be no social and economic progress'), lack of ICT harmfulness (e.g., 'Internet and information technologies do more harm to society than good' (reversely coded), 'New technologies are primarily tools for manipulating people and spreading fake news' (reversely coded), ICT attractiveness (e.g. 'Using the Internet makes me happy', 'The development of information technology makes life more comfortable for all people'), ICT self-efficiency (e.g. 'I feel comfortable using ICT devices such as a computer, smartphone or tablet', 'I freely use electronic forms payments, e.g., internet transfers, payment by phone'). Respondents used a scale from 1 to 5 (1 = strongly disagree, 5 = strongly agree). The psychometric properties of the scale are presented and described in the technical manual (Olech & Jurek, 2022).

To assess dispositional anxiety, the 'Anxiety' subscale (part of the Neuroticism scale) was used from the Revised NEO Personality Inventory (NEO-PI-R) by Costa and McCrae in the Polish adaptation of Siuta (2009). The 'Anxiety' subscale consists of 8 items (e.g., 'I am often worried that something might go wrong') answered on a five-point Likert scale. The reliability

and validity of NEO-PI-R, including its facets, have been well documented in the literature (e.g., Costa & McCrae, 1992).

Age, gender and education were considered as possible confounding variables. These variables were selected due to previous research suggests that they may impact the individual's perception of technology (La Torre, De Leonardis, & Chiappetta, 2020; Tarafdar, Cooper, & Stich, 2019).

RESULTS

All calculations were prepared using the R environment (R Core Development Team, 2020). Means, standard deviations, internal consistency and intercorrelations (r-Pearson) for variables examined in the study are presented in Table 2. As shown, associations between dispositional anxiety and three techno-stressor categories were weak or not significant. Correlations between attitudes towards ICT and perceived technostress dimensions were mostly significant but lower than .30.

Table 2. Descriptive Statistics and Alpha Coefficient for Variables Examined in the Study.

Variable	M	SD	1	2	3	4	5	6	7	8
1/ Dispositional anxiety	3.30	.82	(.83)							
2/ ICT self-efficacy	4.24	.73	.11**	(.77)						
3/ Lack of ICT harmfulness	3.16	.73	-.09	.26**	(.81)					
4/ ICT utility	3.59	.67	-.09*	.39**	.31**	(.71)				
5/ ICT attractiveness	3.87	.72	-.02	.63**	.32**	.54**	(.78)			
6/ Techno-threat	2.86	.99	.20**	-.09	-.28**	-.08	-.11**	(.84)		
7/ Techno-complexity	2.25	.84	.06	-.30**	-.21**	-.11**	-.27**	.44**	(.83)	
8/ Techno-overload	2.61	.87	.15**	-.13**	-.25**	-.05	-.12**	.67**	.57**	(.75)

Notes. $N = 1,037$; *Bonferroni-adjusted p -values at 0.05, **Bonferroni-adjusted p -values at 0.01. Alpha coefficients are given diagonally (in brackets).

Next, we conducted a set of multiple linear regressions, predicting the three techno-stressor categories while learning new app by a way of presenting technology and individual differences, controlling for gender, age and education level. For all tested models, the assumptions for linear regression were verified. For this purpose, the Shapiro-Wilk normality test of residuals was performed. For techno-threat and techno-overload models, the test confirmed the normality of the residual distribution at the level of $p < 0.010$ (respectively: $W = 0.997$, $p = 0.029$; $W = 0.998$, $p = 0.230$). In the case of the techno-complexity model, the Shapiro-Wilk normality test showed a non-normality of residual distribution ($W = 0.983$, $p < 0.001$). However, inspection of quantile-quantile plot showed slight deviations of residuals from the normal distribution. In addition, for each model the error scatter plots were analysed, which confirmed the fulfilment of the assumptions about the linear character of the relationship between the variables and the homoscedasticity of the error distributions.

As seen in Table 3, significant positive associations between dispositional anxiety and three techno-stressor categories still held even after controlling for the attitudes towards ITC

as well as demographic variables. Thus, it supports the hypothesis 1 that individuals with higher dispositional anxiety perceive new technology as more stressful, i.e., more threatening ($\beta = .15$, $p < .001$), more complex ($\beta = .09$, $p < .01$) and more overloading ($\beta = .16$, $p < .001$).

Table 3. Regression Coefficients for Tested Models.

Predictor	Techno-threat			Techno-complexity			Techno-overload		
	B [95% C.I.]	SE	Beta	B [95% C.I.]	SE	Beta	B [95% C.I.]	SE	Beta
Intercept	3.81***	.29		3.53***	.25		2.87***	.25	
<i>Demographic variables</i>									
Gender (male)	-.10 [-.23, .03]	.07	-.05	-.03 [-.14, .08]	.06	-.01	.04 [-.07, .15]	.06	.02
Age	-.01 [-.01, .01]	.01	-.01	.01** [.00, .01]	.01	.10	.01* [.00, .01]	.01	.09
Education (secondary)	-.07 [-.24, .11]	.09	-.03	-.13 [-.28, .02]	.08	-.07	-.18* [-.33, -.03]	.08	-.11
Education (undergraduate or graduate)	-.05 [-.27, .17]	.11	-.02	-.21* [-.40, -.02]	.10	-.11	-.29** [-.48, -.10]	.10	-.15
<i>The way technology is presenting</i>									
Leaflet (compare with scientific paper)	-.19** [-.33, -.05]	.07	-.09	-.02 [-.14, .10]	.06	-.01	-.12* [-.24, -.01]	.06	-.07
Simplified instruction (compare with scientific paper)	-.13 [-.27, .01]	.07	-.06	.01 [-.12, .12]	.06	.00	.08 [-.04, .20]	.06	.04
<i>Individual differences</i>									
Dispositional anxiety	.18*** [.11, .25]	.04	.15	.09** [.03, .15]	.03	.09	.16*** [.10, .22]	.03	.16
ICT self-efficacy	-.05 [-.16, .06]	.06	-.04	-.23*** [-.31, -.12]	.05	-.18	-.05 [-.14, .04]	.05	-.04
Lack of ICT harmfulness	-.36*** [-.44, -.28]	.04	-.28	-.15*** [-.23, -.08]	.04	-.13	-.26*** [-.33, -.19]	.04	-.24
ICT utility	.08 [-.02, .18]	.05	.05	.10* [.01, .19]	.05	.08	.11* [.02, .20]	.05	.09
ICT attractiveness	-.05 [-.16, .06]	.06	-.04	-.16** [-.26, -.06]	.05	-.13	-.01 [-.10, .10]	.05	.00
Model summary									
Adjusted R ²	.11***			.13***			.09***		

Notes. $N = 1,037$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

It was also found that the stronger belief in ICT low harmfulness the less threatening is the newly learned mobile technology ($\beta = -.28$, $p < .001$), less complex ($\beta = -.13$, $p < .001$) and less overloading ($\beta = -.24$, $p < .001$). Further, results presented in Table 3 show that stronger beliefs about ICT self-efficacy and ICT attractiveness are related to perceiving the new technology as less complex ($\beta = -.18$, $p < .001$ and $\beta = -.13$, $p < .01$ respectively). However, no correlation with these dimensions of attitude towards ICT and techno-threat and techno-overload was noted. Additionally, beliefs in ICT utility marginally were related to techno-complexity ($\beta = .08$, $p < .05$) and techno-overload ($\beta = .09$, $p < .05$), but in direction contrary to those predicted in hypothesis 2. In conclusion, the results only partially supported for the hypothesis put forward in this respect.

Finally, results presented in Table 3 show that the way new technology is presented affected perceived technostress but marginally and only in terms of techno-threat ($\beta = -.09$,

$p < .01$) and techno-overload ($\beta = -.07$, $p < .05$). As predicted, getting to know the new technology through a popular science article increases the perceived technostress compared to the situation in which the new technology is presented in the form of a marketing leaflet. The latter serves also as experimental manipulation check.

Since not all effects in the tested models were significant, in the next step the models containing only significant predictors were repeated. Examination of normality of the residuals distribution provided similar results for all three tested models as previously (techno-threat: $W = 0.996$, $p = 0.014$; techno-complexity: $W = 0.983$, $p < 0.001$; techno-overload: $W = 0.998$, $p = 0.208$). As can be seen in Table 4, after the omitting nonsignificant terms, regression coefficients are almost identical when compared to the previously reported results.

Table 4. Regression Coefficients for Tested Models after Omitting Nonsignificant Terms.

Predictor	Techno-threat			Techno-complexity			Techno-overload		
	B [95% C.I.]	SE	Beta	B [95% C.I.]	SE	Beta	B [95% C.I.]	SE	Beta
Intercept	3.59***	.18		3.51***	.25		2.76***	.22	
<i>Demographic variables</i>									
Age	–	–	–	.01** [.00, .01]	.01	.10	.01** [.00, .01]	.01	.11
Education (secondary)	–	–	–	-.13 [-.28, .02]	.08	-.07	-.19* [-.34, -.04]	.08	-.11
Education (undergraduate or graduate)	–	–	–	-.21* [-.40, -.02]	.10	-.10	-.31** [-.49, -.12]	.09	-.16
<i>The way technology is presenting</i>									
Leaflet (compare with scientific paper)	-.18** [-.31, -.04]	.07	-.09	–	–	–	-.12* [-.24, -.01]	.06	-.07
Simplified instruction (compare with scientific paper)	-.13 [-.27, .01]	.07	-.07	–	–	–	.08 [-.03, .20]	.06	.05
<i>Individual differences</i>									
Dispositional anxiety	.19*** [.12, .25]	.03	.16	.09** [.03, .16]	.03	.09	.15*** [.09, .21]	.03	.15
ICT self-efficacy	–	–	–	-.21*** [-.31, -.12]	.05	-.18	–	–	–
Lack of ICT harmfulness	-.37*** [-.44, -.29]	.04	-.28	-.15*** [-.23, -.08]	.04	-.13	-.27*** [-.34, -.20]	.03	-.24
ICT utility	–	–	–	.10* [.01, .19]	.05	.08	.09* [.02, .16]	.04	.07
ICT attractiveness	–	–	–	-.16** [-.26, -.06]	.05	-.14	–	–	–
Model summary									
Adjusted R ²	.11***			.13***			.09***		

Notes. $N = 1,037$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

It should be emphasized that although the direction of a significant part of the relationships between the studied variables was consistent with the hypotheses and these relationships were statistically significant, the regression coefficients are low, so they should be interpreted with great caution. This concern is supported by the analysis of Adjusted R² values for each model tested, which indicates that these models explain between 9 and 13 percent of the variance of the three perceived techno-stressor categories

DISCUSSION

We conducted the current study to explore associations between individual differences (dispositional anxiety, attitudes towards ICT), the way new technology is presented (presentation format of information about technology), and perceived technostress while learning this technology. Specifically, we examined how people perceive techno-threat, techno-complexity, and techno-overload while learning about a new mobile app they haven't used before. As expected, it was found that people characterized by higher dispositional anxiety perceived the new technology as more stressful in terms of all three examined categories of techno-stressors. It was also found that people with more positive attitudes towards ICT (they see it as less harmful) perceived newly learned technology as less stressful. The other dimensions of attitudes towards ICT turned out to be irrelevant for predicting the perceived technostress (except techno-complexity) while learning a new technology at the early stage. Finally, it was found that presenting the new technology in the form of a popular science article was associated with the perception of this technology as more threatening and overloading (but not complex) compared to the situation in which the technology was presented in the form of a marketing leaflet with an unequivocally positive message.

Although most of the hypotheses were supported by the results obtained, it should be noted that the effect sizes are small and the models explain the marginal variance of the perceived technostress. There are at least two reasons for a weak relationship between dispositional anxiety, attitudes towards ICT, and perceiving the new technology as stressful indicated in the current study. First, a person's reaction to a given technology is primarily driven by their individual experience of using it. Although, it may seem that the exacerbated intensity of technostress may stem from personality and more generic attitudes towards ICT, the most indicative source of technostress is one's negative experience derived from either learning or utilising some specific technological solutions (Day et al., 2019). Only encountering technical difficulties or experiencing negative consequences of the operation of technology (task overload, task pressure, interpersonal misunderstandings, etc.) has the potential to evoke clear emotional and physiological reactions that are signals of technostress. Learning about technology in a theoretical rather than practical manner as arranged in the present study may not be a sufficient impetus to elicit an arousal that detects individual differences in responding to the new technology.

Secondly, the context of using the technology seems to be the key factor for experiencing technostress. In work-related conditions, the usage of technologies is often mandated, employees have no option other than to use them. In private life, the use of ICT serves to meet a different kind of need, the satisfaction of which usually makes it possible to choose between different technological solutions available. Besides, individuals can typically stop using a technology when they perceive technostress, which obviously does not change the fact that individuals also perceive stress when using IT privately (La Torre et al., 2019). However, the technostress antecedents and its harmfulness may be different depending on the context of use. In our study, the exposed mobile application had a potential use in personal life, in the field of monitoring the user's health. The participants of the study did not face the necessity to use this technology, which probably contributed to an emotionless assessment of this mobile application.

The obtained results support the concept of individual and situational determinants of the perception of new technologies, despite the fact that in the current study small effect sizes were received. At the same time, finding weak relationships between individual differences, the form of technology presentation and technostress in the initial stages of encountering new technology can contribute to planning future research. It can be assumed that the potential perception of technology as a source of stress develops only in the phase of using the technology. Then, not only unique experiences, but individual differences may play a greater role. Thus, cautiously, due to rather low effects size, we suggest the process of learning new pro-healthy app implemented in a smooth, positive way. Descriptions how to use the app might indicate the simplicity of a given technology, its affability and utility.

LIMITATIONS OF THE STUDY

The first limitation of the study are rather low effects sizes. This unables us to generalize the results on the whole population of Poles. The research however seems to be the first step towards creation of the new manner of implementation new pro-healthy apps. Literature on Virtual Environment (VE) shed light on vast majority of clinical approach to rehabilitation and therapeutic practises, immersed in Virtual Reality (VR) (Wojciechowski, Wiśniewska, Pyszora, Liberacka-Dwojak, & Juszczuk, 2021). The contemporary development requires new, good tools for creative and positive VT implementation.

Second, we designed a study in which learning about a new technology was based on written materials (early phase of contact with technology), while examining technostress may be more rationale when using new technology. Only when trying a new application or device, the user has the opportunity to experience negative emotions related to the difficulties encountered (Day, Barber, & Tonet, 2019). Thus, it is necessary to design experiments in which the participants could face the necessity to actually use new ITC solutions.

Finally, the use of technology in everyday life should be developed in future research. Until now, technostress researchers mainly have focused on experiences of using technology in work or education context, where the choice of users is limited (they must learn a new technology in order to fulfill their responsibilities). We still don't know much about the technostress that accompanies the use of technology in everyday life. Here, the type of pressure exerted may have a different character, e.g., related to belonging to a social group or self-presentation. There is a need to extend research to include such determinants of human-technology interaction.

REFERENCES

- Ayyagari, R., Grover, V., & Purvis, R. (2011). Technostress: Technological antecedents and implications. *MIS Quarterly: Management Information Systems*, 35(4), 831–858. <https://doi.org/10.2307/41409963>
- Barlow, D. H. (1988). *Anxiety and its disorders: The nature and treatment of anxiety and panic*. New York, NY: Guilford Press.
- Borle, P., Reichel, K., Niebuhr, F., & Voelter-Mahlknecht, S. (2021). How Are Techno-Stressors Associated with Mental Health and Work Outcomes? A Systematic Review of Occupational Exposure to Information and

- Communication Technologies within the Technostress Model. *International Journal of Environmental Research and Public Health*, 18(16). <https://doi.org/10.3390/ijerph18168673>
- Brod, C. (1982). Managing technostress: Optimizing the use of computer technology. *Personnel Journal*, 61, 753–757.
- Costa, P. T., & McCrae, R. R. (1992). *Professional manual: revised NEO personality inventory (NEO-PI-R) and NEO five-factor inventory (NEO-FFI)*. Odessa, FL: Psychological Assessment Resources. <https://doi.org/10.1037/1040-3590.4.1.5>
- Day, A., Barber, L. K., & Tonet, J. (2019). Information Communication Technology and Employee Well-Being. In *The Cambridge Handbook of Technology and Employee Behavior* (pp. 580–607). <https://doi.org/10.1017/9781108649636.022>
- Devaraj, S., Easley, R. F., & Crant, J. M. (2008). Research Note: How Does Personality Matter? Relating the Five-Factor Model to Technology Acceptance and Use. *Information Systems Research*, 19(1), 93–105. Retrieved from <http://www.jstor.org/stable/23015423>
- Fischer, T., Pehböck, A., & Riedl, R. (2019). Is the Technostress Creators Inventory Still an Up-To-Date Measurement Instrument? Results of a Large-Scale Interview Study. *14th International Conference on Wirtschaftsinformatik*, 1820–1852. Siegen.
- Kelton, A. S., Pennington, R. R., & Tuttle, B. M. (2010). The Effects of Information Presentation Format on Judgment and Decision Making: A Review of the Information Systems Research. *Journal of Information Systems*, 24(2), 79–105. <https://doi.org/10.2308/jis.2010.24.2.79>
- Krishnan, S. (2017). Personality and espoused cultural differences in technostress creators. *Computers in Human Behavior*, 66, 154–167. <https://doi.org/https://doi.org/10.1016/j.chb.2016.09.039>
- La Torre, G., De Leonardis, V., & Chiappetta, M. (2020). Technostress: how does it affect the productivity and life of an individual? Results of an observational study. *Public Health*, 189, 60–65. <https://doi.org/https://doi.org/10.1016/j.puhe.2020.09.013>
- La Torre, G., Esposito, A., Sciarra, I., & Chiappetta, M. (2019). Definition, symptoms and risk of techno-stress: a systematic review. *International Archives of Occupational and Environmental Health*, 92(1), 13–35. <https://doi.org/10.1007/s00420-018-1352-1>
- Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education*, 84(1), 71–94.
- Lee, Y.-K., Chang, C.-T., Lin, Y., & Cheng, Z.-H. (2014). The dark side of smartphone usage: Psychological traits, compulsive behavior and technostress. *Computers in Human Behavior*, 31, 373–383. <https://doi.org/https://doi.org/10.1016/j.chb.2013.10.047>
- Maier, C., Laumer, S., Wirth, J., & Weitzel, T. (2019). Technostress and the hierarchical levels of personality: a two-wave study with multiple data samples. *European Journal of Information Systems*, 28(5), 496–522. <https://doi.org/10.1080/0960085X.2019.1614739>
- Olech, M., & Jurek, P. (2022). *TECHNOSTRES. Skale do pomiaru sposobu postrzegania technologii* [TECHNOSTRESS. Scales for measuring the perception of technology]. Gdańsk: Pracownia Testów Psychologicznych i Pedagogicznych.
- R Core Development Team. (2020). *R: A language and environment for statistical computing*. Retrieved from <http://www.r-project.org/>.
- Ragu-Nathan, T. S., Tarafdar, M., Ragu-Nathan, B. S., & Tu, Q. (2008). The consequences of technostress for end users in organizations: Conceptual development and validation. *Information Systems Research*, 19, 417–433. <https://doi.org/10.1287/isre.1070.0165>
- Shepperd, J. A., Grace, J., Cole, L. J., & Klein, C. (2005). Anxiety and outcome predictions. *Personality & Social Psychology Bulletin*, 31(2), 267–275. <https://doi.org/10.1177/0146167204271322>
- Shu, Q., Tu, Q., & Wang, K. (2011). The impact of computer self-efficacy and technology dependence on computer-related technostress: A social cognitive theory perspective. *International Journal of Human-Computer Interaction*, 27, 923–939.

- Siuta, J. (2009). *Inwentarz Osobowości NEO-PI-R Paula T. Costy Jr I Roberta R. McCrea. Adaptacja polska. Podręcznik*. Warszawa: Pracownia Testów Psychologicznych PTP.
- Srivastava, S. C., Chandra, S., & Shirish, A. (2015). Technostress creators and job outcomes: Theorising the moderating influence of personality traits. *Information Systems Journal*, 25(4), 355–401. <https://doi.org/10.1111/isj.12067>
- Tarafdar, M., Cooper, C. L., & Stich, J.-F. (2019). The technostress trifecta - techno eustress, techno distress and design: Theoretical directions and an agenda for research. *Information Systems Journal*, 29(1), 6–42. <https://doi.org/https://doi.org/10.1111/isj.12169>
- Tarafdar, M., Tu, Q., Ragu-Nathan, B. S., & Ragu-Nathan, T. S. (2007). The impact of technostress on role stress and productivity. *Journal of Management Information Systems*, 24, 301–328. <https://doi.org/10.2753/MIS0742-1222240109>
- Wojciechowski, A., Wiśniewska, A., Pyszora, A., Liberacka-Dwojak, M., & Juszczuk, K. (2021). Virtual reality immersive environments for motor and cognitive training of elderly people – a scoping review. *Human Technology*, 17(2), 145–163. <https://doi.org/10.14254/1795-6889.2021.17-2.4>

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Human Technology
ISSN 1795-6889
<https://ht.csr-pub.eu>

Appendix

Three Ways of Presenting the New Technology Used in the Study Condition A



Czym jest Felicit?

Aplikacja Felicit to innowacja medyczna testowana już w kilku krajach (m.in. w Niemczech i Japonii). System składa się z trzech elementów: opaski na nadgarstek (m.in. pomiar tętna i temperatury), aparatu do badania wielu wskaźników fizjologicznych ze śliny oraz aplikacji mobilnej. Pierwszy element jest już standardowym wyposażeniem prawie każdego sportowca. Proponowany w Felicity model jest może nieco bardziej zaawansowany technicznie, ale to nadal solidny standard. Drugi element zestawu to prawdziwe dzieło inżynierii, biochemii i nauk o fizjologii człowieka. Urządzenie SalivamPRO przeprowadza badanie poprzez polizanie paska papieru (dosłownie!). Wynik badania (w tej chwili obejmujący około 20 wskaźników) jest gotowy do odbioru w 5 minut. To wszystko z urządzenia niewiele większego niż pudełko po butach. Trzeci element to aplikacja na telefon komórkowy lub tablet, spajająca oba poprzednie elementy i będąca swoistym centrum dowodzenia systemem.

Jakie są możliwości Felicit?

Zakres i częstotliwość zbieranych przez aplikację danych to kopalnia wiedzy o codziennym samopoczuciu człowieka. Ponieważ Felicit jest sprzężona z systemami instytucji ochrony zdrowia (przychodnie, ubezpieczyciele), to informacje o zdrowiu osoby mogą być błyskawicznie przekazane do jej lekarzy zanim pomyśli się o wizycie.

W szczególnych przypadkach aplikacja będzie wywierać na użytkownika presję, aby zadbał o siebie i skorzystał z konsultacji medycznej. Co więcej, w razie utraty przytomności, system automatycznie łączy się z odpowiednimi służbami ratowniczymi, przekazując im odczyty systemowe. Dzięki temu, nawet jeżeli aktualnie osoba jest sama, służby medyczne niezwłocznie dotrą do niej z pomocą.

Czy dane o naszym zdrowiu mogą być wykorzystane wbrew naszemu interesowi?

Oczywiście przy okazji testów Felicit nikt nie wspomina o tym, kto będzie miał dostęp do tak wrażliwych danych i jak przeciwdziałać by nie trafiły w niepowołane ręce. A katalog informacji gromadzonych przez Felicit jest bezprecedensowo wrażliwy – nawet dane zapisywane w kartach wizyt lekarskich nie są tak dokładne i tak wiele mówiące o naszym codziennym życiu, jak to co będą przechowywały serwery Felicit.

O autorze: Dr Andrew Weber jest lekarzem i socjologiem, od wielu lat prowadzi badania nad bezpieczeństwem danych medycznych.

Condition B

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Stan twojego zdrowia pod kontrolą 24 godziny na dobę



Dzięki Systemowi Felicite będziesz 24 godziny na dobę pod opieką lekarzy specjalistów. Na system składa się elegancka opaska na nadgarstek, prosty w obsłudze, lecz bardzo zaawansowany system diagnozy domowej oparty na ślinie SalivamPRO oraz intuicyjna aplikacja mobilna do śledzenia stanu swojego zdrowia.

Jak działa Felicite?

- Dzięki opasce i łatwym do wykonania testom diagnostycznym aplikacja codziennie analizuje stan twojego organizmu i informacje na ten temat bezpośrednio przekazując dane do specjalistów dbających o twoje zdrowie.
- Otrzymujesz rekomendacje dotyczące wizyt u lekarzy pierwszego kontaktu lub specjalistów. W prosty sposób skracasz sobie drogę umawiania wizyt oraz redukujesz czas marnowany zazwyczaj na wstępną diagnostykę twojego stanu zdrowia – przychodzisz do lekarza z więcej niż podstawowym zakresem diagnozy.
- W razie utraty przytomności lub zapaści, system automatycznie łączy się z odpowiednimi służbami ratowniczymi, przekazując im odczyty systemowe. Dzięki temu, nawet jeżeli aktualnie jesteś sam, służby medyczne dotrą do ciebie niezwłocznie, gotowe do udzielenia odpowiedniej pomocy.
- Sam ustalasz zakres diagnozy oraz częstotliwość, z jaką ją wykonujesz. Zalecamy jednak nieprzerwane korzystanie z opaski diagnostycznej oraz wykonywanie badań śliny urządzeniem SalivamPRO co najmniej raz w tygodniu.
- Udostępniasz dane tylko wtedy, kiedy chcesz. Wszyscy ubezpieczyciele i państwowe systemy ochrony zdrowia dochowują najwyższych standardów dbania o prywatność twoich danych. Możesz również samemu ograniczyć zakres danych wysyłanych gdziekolwiek poza twój telefon.
- Pomagasz innym, ponieważ dzięki danym z twojego osobistego systemu diagnozy możemy lepiej zrozumieć wiele schorzeń i uczymy się jak efektywniej dbać o zdrowie twoje i innych.



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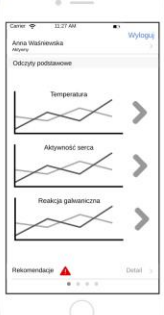
Condition C



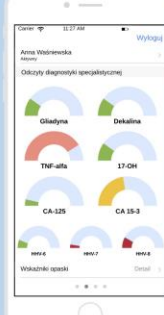
Założ opaskę diagnostyczną na nadgarstek. Nie ma znaczenia czy prawy, czy lewy. Uruchom ją przyciskiem po prawej stronie. Urządzenie natychmiast rozpocznie pracę. Wbudowany moduł Bluetooth wysle sygnał do urządzeń w pobliżu i sprawi, że opaska będzie gotowa do powiązania jej z telefonem lub tabletem, na którym zainstalowano aplikację mobilną systemu Felicit.



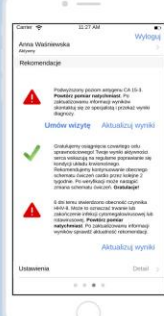
W aplikacji zobaczysz również rezultaty diagnozy aparatemSalivamPRO. Zakres proponowanych przez urządzenie analiz będzie z czasem coraz szerszy. Informacje z aplikacji powędrują do specjalnych algorytmów, które m.in. dzięki sztucznej inteligencji będą w stanie ocenić czy któryś z zaobserwowanych wskaźników nie jest zbyt niski lub zbyt wysoki. Analiza tych danych odbywać się będzie na dotychczas niespotykanym poziomie kompleksowości i dokładności.



Aplikacja mobilna systemu Felicit to przede wszystkim mechanizm podsumowywania i rejestrowania historii twoich pomiarów. To platforma, gdzie możesz w wygodny sposób przeglądać, jak kształtowały się parametry twojej fizjologii na przestrzeni czasu – sam określasz jaki okres cię interesuje; sam wybierasz który aspekt twojego funkcjonowania najbardziej cię interesuje



W aplikacji zobaczysz również rezultaty diagnozy aparatemSalivamPRO. Zakres proponowanych przez urządzenie analiz będzie coraz szerszy. Informacje z aplikacji powędrują do specjalnych algorytmów, które m.in. dzięki sztucznej inteligencji będą w stanie ocenić czy któryś z zaobserwowanych wskaźników nie jest zbyt niski lub zbyt wysoki. Analiza tych danych odbywać się będzie na dotychczas niespotykanym poziomie kompleksowości i dokładności.



Wszystkie informacje o tobie posłużą Felicit do dbania o twoje codzienne samopoczucie. W sekcji rekomendacji znajdziesz porady jak ćwiczyć, co jeść, kiedy pracować oraz kiedy spać – wszystko to, aby zachować dobre samopoczucie, kondycję oraz idealne parametry fizjologiczne. Gdy tylko aplikacja wykryje niebezpieczne wskazania, poinformuje cię o tym i pomoże w kontakcie z lekarzem lub służbami ratowniczymi.



Aby zapewnić komfort użytkowania Felicit, dostępny masz szeroki wachlarz opcji zarządzania informacjami gromadzonymi w trakcie diagnozy i codziennego użytkowania. Jeżeli zdecydujesz się na korzystanie z naszych systemów monitorujących, zapewnimy ci daleko idącą transparentność polityki przetwarzania danych oraz dochowamy wszelkich starań, by twoje dane były bezpieczne. Swoją aplikację możesz powiązać z systemem informatycznym swojego ubezpieczyciela (lista współpracujących ubezpieczycieli ciągle się powiększa) i w ten sposób jeszcze bardziej skrócić sobie czas oczekiwania na wizytę, a nierzadko i obniżyć składkę ubezpieczenia zdrowotnego.

THE TEMPORAL INFERENCE WITH THE USE OF ANT-BASED CLUSTERING ALGORITHM AND FLOW GRAPHS IN THE PROBLEM OF PROGNOSING COMPLICATIONS OF MEDICAL SURGICAL PROCEDURES

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Abstract: *In the era of a rapidly aging European society, the demand for proven clinical decision support systems, links health observations with medical knowledge in order to assist clinicians in decision making is constantly growing. An increasing problem for this type of systems is not only the size of the processed data sets but also the heterogeneity of these data. Clinical forecasting often requires processing of both numerical data and multi-category data which are temporal. The conducted research has shown that a good solution to this problem may lie in the use of temporal inference, the ant-based clustering algorithm, rough sets, and fuzzy sets. The experiments used a real set of medical data representing cases of a disease that significantly reduces a woman's quality of life. Each case of uterine myoma disease (which affects more than 50% of women over the age of 35) is represented by more than 140 heterogeneous features. An incorrect decision about the type of surgery (thermoablation or surgery) not only affects female fertility but also the high risk of complications. Therefore, the solution discussed in this paper may turn out to be extremely important.*

Keywords: *temporal inference, flow graphs, rough sets, fuzzy sets, ant-based clustering.*



INTRODUCTION

The fast growth in the amount of available information collected in an electronic form and the development of digital data acquisition and recording technologies means that the techniques of exploring and discovering knowledge in data are used in an increasing number of fields. However, this requires an interdisciplinary approach. The domain data must be properly understood before the essential features of the available data set can be selected. Only then we can start coding, normalizing, exploring and analysing data. The data mining becomes a key tool for the competitive advantage of companies in terms of discovering patterns and dependencies, constructing analytical models, assessing the degree to which models fit the data and interpreting the results. It also revolutionizes all areas related to the quality of human life, primarily in terms of protection and improvement of human health. Therefore, in medicine, the demand for data analysis tools that use automatic and semi-automatic methods to identify and describe patterns, trends, or relationships in data is growing more than ever. However, this is associated with many difficulties. The basic problem is that the collected data resources have many incomplete features. The data are heterogeneous because they include not only numerical values (integer and real values) but also categorical values and multi-categories. In addition, the data require the application of various fields of data science due to the need to process multidimensional data structures, including irregularly sampled processes with space-time dependencies. The results of the research on available medical databases, which were recently published in *The Lancet Digital Health* (Wen et al., 2021) clearly show the problem of the lack of complete data. According to the authors, machine learning algorithms, that are to help in the early detection of dangerous diseases (e.g. skin cancer), learn from incomplete databases. Consequently, their effectiveness cannot be guaranteed. This has also been confirmed in other studies (Daneshjou, Smith & Sun, 2021; Pawlowski, 2019). In addition, the available medical data resources include multidimensional heterogeneous data structures (in the form of time series, numerical data, categorical data and image files). It is a significant challenge in terms of correct data preprocessing, so that the processed data resources can be used effectively (Thirumahal, Sadasivam, 2020; Ren, Lu, Wang, 2018). The correct approach to machine learning requires the analysis of data structure and relationships, development or selection of an appropriate model of inference, as well as visualization and interpretation of the obtained results. Therefore, the analysis and inference are carried out using both quantitative and qualitative methods. This approach takes into account linear, nonlinear, discrete and continuous models, including data reduction algorithms, feature extraction, data discretization, decision rule generation, neural network models, frequency analysis models, and many statistical analysis tools and models. However, most of them work well when dealing with a large number of samples, a small amount of missing data and multi-criteria data. In any other case (Salcedo-Bernal, Villamil-Giraldo, Moreno-Barbosa, 2016; Dhillon & Singh, 2019), a different method is used that will allow the achievement of satisfactory results (relating to an acceptable error value at the output). These include solutions using fuzzy sets (Vlamou, Papadopoulos, 2019) or rough sets (Burney & Abbas, 2015). They allow inference based on heterogeneous data sets, but require complete data sets. Therefore, in the opinion of the authors of the article, the appropriate approach to the problem may be the use of an ant-based clustering algorithm and flow graphs. The ant-based clustering algorithm is an example of the algorithm that does not require specifying the expected number of clusters. This is a significant advantage as compared

to the most frequently used: K-means algorithm, hierarchical algorithms or Gaussian Mixture algorithm (Su, Dy, 2007). The approach presented in the article was tested on a real medical data set.

The analytical process of knowledge discovery to support decision-making always requires proper data preparation (Tripathi, Muhr, Brunner, Jodlbauer, Dehmer & Emmert-Streib, 2021; Alnoukari & El Sheikh, 2012). Therefore, data validation, cleansing, re-encoding and variable selection are performed. The data encoding process includes transformation, cleansing and data quality assessment. Feature fields with missing data must be properly completed or marked. The next step is to select the features for analysis, because not all variables will be meaningful or valuable in the proposed solution. In addition, all data should be normalized. A data set prepared in such a way can be processed by an appropriate decision inference algorithm. This is shown in Figure 1.

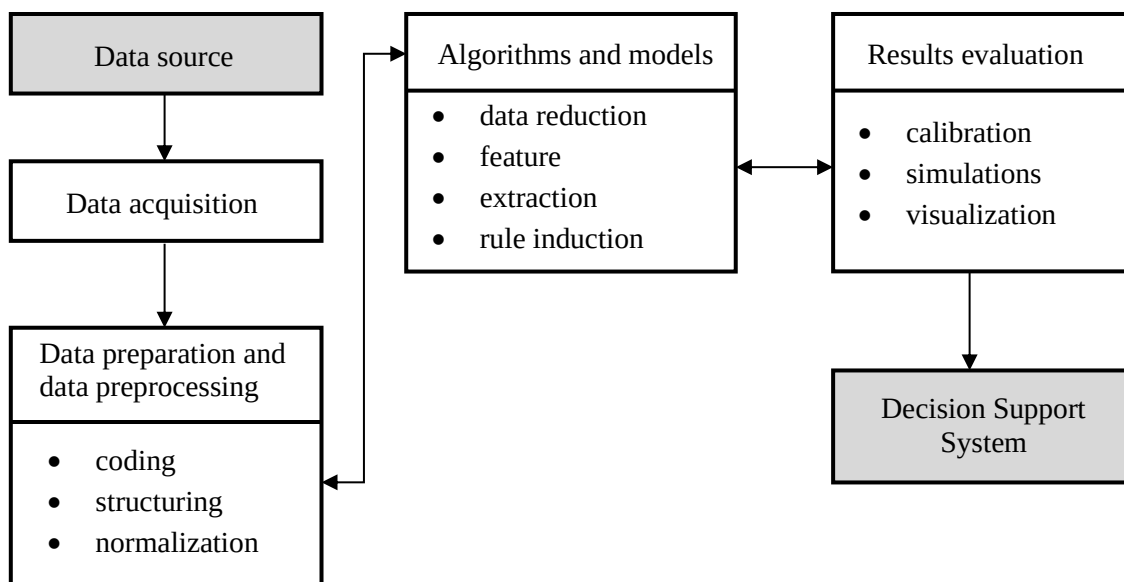


Figure 1. Data processing model for forecasting purposes.

The decision support system based on the mechanisms of relational analysis of the aggregated features of the available data set is a solution expected in many fields of medicine. One of them is gynaecology. No proven solution to the problem of predicting the effectiveness of thermoablation of fibroids treatment has been developed so far in this medical field. Currently, the qualification of the patient for the treatment of thermal ablation of fibroids is based on a gynecologist's consultation with a radiologist. However, the research conducted has shown (Lozinski, Filipowska, Gurnowicz, Pyka, Ciebiera, 2020) that it is not always the right decision. Uterine fibroids are benign tumours of the female reproductive organs (De La Cruz & Buchanan, 2017). They affect even every fourth woman of childbearing age. The patient is usually referred for removal of the uterine body or the entire uterus in the event of heavy bleeding, abdominal pain and anaemia. However, it is associated with the loss of female fertility. The ultrasonic thermoablation treatment is a hope for its preservation. The ultrasonic thermoablation is a non-invasive procedure (Kalamarz, Zagrobelna & Pyziak, 2017) that has only been used in gynaecology for several years. It uses a 3-Tesla device. The energy of the

focused ultrasound beam generated by this device is precisely directed from ultrasound or magnetic resonance imaging. The high-frequency ultrasound wave causes a temperature increase in the range of 60-100 degrees in the target tissue, protein denaturation and tumour degradation as a result. However, the ultrasonic thermoablation treatment is very expensive. The decision about the positive qualification of the patient for the procedure of ablation is now made by doctors on the basis of 4 features selected from a set of over 140 features representing the detailed results of diagnostic tests. The analysis usually concerns only such features as: the location of the myoma, its relation to the environment, the thickness of the adipose tissue and the type of myoma according to the Funaki classification (Sainio, Saunavaara, Komar, Mattila, Otonkoski & Joronen, 2021). However, the available literature (Lozinski, Filipowska, Gurynowicz, Pyka & Ciebia, 2020; Verpalen, Anneveldt, Nijholt, Schutte, Dijkstra, Franx, Bartels, Moonen, Edens & Boomsma, 2019) and the analysis of the available control results of 218 patients after 6 and 12 months show that this approach is only associated with an accuracy of 25% to 35% (Lozinski, Filipowska, Gurynowicz, Pyka, Ciebia, 2020). Therefore, we have created and next evaluated an IT system of decision support for the problem defined above.

The proposed approach is related to the analysis of data containing information obtained before the procedure and 3 and 6 months after the thermoablation procedure. The data collection procedure results from the standard medical procedure adopted by the physicians in the considered medical problem. It is possible to achieve valuable knowledge by building a flow graph in which nodes represent specific clusters determined on the basis of features related to a given temporal information. The use of data collected by physicians does not give satisfactory results in qualifying patients for thermoablation. Hence, there is a need to use machine learning tools to extract knowledge from data. Each node represents a specific time event and information about the affiliation of each processed data vector to a specific group of objects with similar characteristics. Therefore, data sets related to significant temporal features must be clustered in advance in order to create a flow graph. This is due to the fact that vectors are created in different feature spaces describing patients at distinguished moments in time. Which features appear at each stage depends on the medical procedure determined by physicians. Therefore, there is no one feature space considered in all stages. The rationale behind the clustering and flow graph approach is the desire to link two perspectives in the inference problem under consideration: a spatial perspective (clustering in feature spaces) and a temporal perspective (information flow over time represented by a flow graph). The metaheuristic ant-based algorithm was used due to multidimensional data structures, missing data and the inability to indicate the number of result groups for this purpose. The authors of the article did not find other solutions allowing for effective inference from incomplete multidimensional data.

The data set used in our study was obtained thanks to cooperation with a medical clinic. It contains 145 heterogeneous features (including integer, real, categorical and multi-category values) and 218 data records. Each of the 218 data vectors represents a separate patient with severe symptoms of uterine fibroids. The data set was initially processed and then divided into 3 subsets (with different features), representing respectively the test results necessary to make a decision about thermoablation treatment and its implementation, the results of control tests performed 3 months after the procedure and the results of control tests performed 6 months after the procedure. The data feature interdependencies are determined by physicians on the

basis of adopted medical procedures and the medical knowledge available. The first of the processed data subsets is the data set of medical test results before the thermal ablation procedure. These data include blood counts, ultrasound, detailed medical history, history of diseases, history of pharmacological treatment, measurements of the size of each detected myoma and detailed gynecological diagnostics. This set consists of 91 unique features. The second collection concerns the results of the patient's control test, 3 months after the procedure. It consists of 29 different features from those in the first data set. These data include the results of ultrasonography performed 3 months after the thermoablation treatment, post-treatment NPV and magnetic resonance imaging. The last subset of data processed is a set of another 25 unique features. They represent the patient's control test results 6 months after the thermal ablation procedure. The physicians define the range of the patient's control test at each stage. Therefore, there does not exist any fixed relationship between features from particular collections. There is only a relationship resulting from the physician's decision in regard to the scope of the tests. All non-numeric feature values (including categorical values) in the above data sets have been encoded as numerical data. The one-hot encoding method was used for this purpose and then the data was normalized. One-hot encoding is a process in data processing that is applied to categorical data in order to convert it into a binary vector representation. Individual values of such a vector can then be represented as a sequence of features. An exemplary (1 of 218) input data vector of a data subset is shown below:

[1.0;1.0;1.0;0.27586;0.4;0.96753;0.0;0.0;0.0;0.0;0.0;0.0;0.058823;1.0;0.0;0.0;0.0;1.0;1.0;1.0;1.0;0.0;1.0;0.0;0.0;0.0;1.0;0.0;0.0;0.0;0.0;0.0;0.0;0.0;1.0;1.0;0.00151;0.68582;0.67677;0.48078;0.21003;0.027399;0.362076;0.009971;0.17734;0.01397;0.350981;0.00491;0.33333;0.62616;0.55652;0.56140;0.27447;0.6875;0.0;0.0;0.8;0.24137;0.0;1.0;0.84347;0.62385;0.60629;0.40255;0.0;0.0;0.0;0.0;0.0;0.0;1.0;0.0;0.0;1.0;0.0;0.0;0.0;0.46341;0.0;0.03678;0.23990;0.42433;0.325;0.23529;0.27234;0.10455;0.64285;0.44;1.0;1.0;0.42307;2.0]

The subsets were clustered and a flow temporal inference graph was built. There are many algorithms for grouping a set of objects in such a way that objects in the same group are more similar to each other than to those in other groups (Singh, Srivastava, 2020). The division can be made according to data types (e.g. numbers, text data, images, etc.), the mechanism of generating clusters (deterministic and probabilistic algorithms) or the method of obtaining clusters (hierarchical and flat algorithms). Unfortunately, many traditional clustering algorithms have many disadvantages. They are primarily computationally inefficient because they work well for a small number of features of grouped data. They are also sensitive to outliers. At this point, it is important to refer to (Handl, Knowles, Dorigo, 2003), where the authors discuss the advantages of using the ant-based clustering algorithm over other clustering algorithms. Among other things, the authors draw attention to the following facts: (i) the nature of the ant-based algorithm makes it fairly robust to the effects of outliers within the data, (ii) ant-based clustering has the capacity to work with any kind of data that can be described in terms of symmetric dissimilarities, and it imposes no assumption on the shape of the clusters it works with. Moreover, other clustering algorithms often also require a priori information about the number of expected clusters. However, heuristic algorithms deal with these problems well. One of them is the ant-based clustering algorithm (Boryczka, 2008; Pancierz, Lewicki, 2012).

The flow graph is a suitable tool to model information flow in case of heterogeneous domains. As it will be shown in the next sections, we cannot treat our problem in terms of time series analysis, because we do not deal with the same quantities changing in time.

METHODOLOGY

Algorithm of Ant Collective Intelligence in the Task of Data Clustering

The ant-based clustering algorithm (Boryczka, 2008; Pancerz, Lewicki, 2012) is a population-based algorithm in which subsequent generations of virtual ant are looking for good quality solutions. It was created on the basis of observation of the ability of ants to stack the bodies of dead ants (Deneubourg, Goss, Franks, Sendova-Franks, Detrain & Chretien, 1991). Its basic operating principle relates to the ability of the agent (ant) to pick up, transport and drop items. The possibility of picking up and dropping an element is determined by the probability. The value of the probability depends on the neighbouring elements in the available search space. Ants prefer to pick up objects that are isolated or adjacent to different objects. Moreover, they tend to drop objects that are in the vicinity of similar objects. Objects are grouped within the explored area as a result of this approach. The Ant-based clustering algorithm does not use the phenomenon of leaving a pheromone trace. Moreover, the size of the ant (agent) population does not have a large impact on the algorithm's performance.

The ant-based clustering algorithm was used first to group the first set of objects, then to group the second set of objects, and after that to the third set. The first data set was a set of patient test results prior to the uterine myoma ablation procedure. This set consists of 218 data vectors. Each vector represents a different patient and it is described by 91 unique features. Each of the values of the processed features (after carrying out the coding and normalization process) was a numerical value. Each vector of this set consists of the same number of features, which give information on: past thermoablation, operations, contraindications (that we know), patient's age, weight, height, number of births, number of miscarriages, obstruction of the fallopian tube, anovulation, partner's sperm, date of first myoma detection, heavy menstruation, anemia, HB before the procedure, intermenstrual bleeding, abdominal pain, painful menstruation, painful intercourse, pressure on the bladder, pressure on the rectum, attempts to treat fibroids or fibroids, as well as laparoscopy data, ultrasound data, detailed information on the size of each detected myoma and information about its position. The second set of data was the results of the patients' control tests performed 3 months after the thermoablation procedure. Data vectors of this set were represented by attributes corresponding to such features as: change in the volume of the myoma, position in relation to the uterus, position in relation to the abdominal cavity, length of the myoma, width of the myoma, volume of the myoma visualized using ultrasound, menstrual bleeding, bleeding between periods, soreness of menstruation, the patient's well-being, NPV, quality of life, Funaki classification of myoma size change, the degree of hardness of the lower abdomen, evaluation of the pressure on the bladder, parameters of ultrasound examination with contrast and MRI parameters. This set was also converted into numerical values after the coding and normalization process. These features (apart from the contrast ultrasound) also represented the third data set. The third set of data was the results of the patients' control tests performed 6 months after the thermoablation procedure. Each of the three sets listed above consisted of 218 data vectors. The expected result of grouping each object of the first, second and third data set was the information about the cluster number in which the object was placed. In general, there is no requirement that the feature sets defined at each stage are related to each other. The physicians define the range of the examination at each stage. In the extreme case, the patient may be described by a completely different set of features

at each stage. The only determinant is the fact that these features allow physicians to determine the condition of the patient at a given time for the selected disease entity.

Objects representing the input data vectors (recordset) were randomly placed in space (in the form of a toroidal grid) in the initialization phase. The number of agents (ants) was set to the same value as the number of data vectors processed (218). Each agent has been associated with a different object and placed on the grid at random coordinates. The next step was to iterate for a given value. Experiments showed that the best results were obtained for a value equal to 500. Each agent moved randomly around the grid picking and dropping the data objects. The decision of dropping an object depended on the calculated probability value. The probability of dropping an object was given by a formula:

$$P_d(o_i) = \begin{cases} 1, & \text{if } f(i) \geq 1 \\ \frac{1}{f(i)^4}, & \text{else} \end{cases}$$

where:

- $P_d(o_i)$ is the probability of dropping object o_i ,
- $f(i)$ is a modified version of Lumer and Faieta's neighbourhood function (Lumer, Faieta, 1994).

The neighbourhood function $f(i)$ was given by formula:

$$f(i) = \begin{cases} \frac{1}{\delta^2} \sum_j \left[1 - \frac{d(i,j)}{\alpha} \right], & \text{if } f > 0 \text{ and } \left(1 - \frac{d(i,j)}{\alpha} \right) > 0 \\ 0, & \text{otherwise} \end{cases}$$

where:

- $d(i, j)$ is the dissimilarity (Euclidean distance) between a pair of objects (o_i, o_j),
- α is a factor that defines the scale for dissimilarity,
- δ^2 is a neighbourhood size ($\delta^2 \in \{9; 25\}$).

A modification of the Lumer and Faieta algorithm was applied here in order to improve convergence due to the fact that the problem under consideration concerns the grouping of data in the context of knowledge discovery. The algorithm without a modified version of Lumer and Faieta's neighbourhood function was less efficient (Pancerz, Lewicki, 2012).

The similarity function was computed on the basis of the Euclidean distance. The agent left the object where it currently was on the grid in case of decision to drop an element. He searched for a new object to pick up at the next step. It was related to the probability function defined by formula:

$$P_p(o_i) = \begin{cases} 1, & \text{if } f(i) > 1 \\ \frac{1}{f(i)^2}, & \text{otherwise} \end{cases}$$

where:

- $P_d(o_i)$ is the probability of picking object o_i ,

$C \cup D$, where C is the nonempty, finite set of condition attributes, D is the nonempty, finite set of decision attributes. We often consider a decision system with one decision attribute, i.e., $D = \{d\}$.

Any information system can be presented as a data table. Columns of the table are labelled with attributes from the set A , rows are labelled with objects from the set U , and entries of the table are values of the attribute function f assigning to each attribute $a \in A$ and each object $u \in U$, a value of a on u .

In the approach presented in this paper, we consider an information system $IS = (U, A, \{V_a\}_{a \in A}, f)$ in which a set A of attributes is ordered in time, i.e., $A = \{a_t: t = 1, 2, \dots, m\}$. The subscript t can be treated as the time point identifier. We assume that the time space is discrete. Such an information system will be called a temporal information system.

The values of attributes can represent different entities, for example, results of measurements, observations or calculations. In the approach presented in this paper, the values of attributes represent clusters of objects, i.e., each value is a cluster identifier.

Figure 2 shows a general idea of acquiring input data. At the beginning, input data consist of objects (in our case, patients) described by sets of features specified in a given time space. Hence, for each object, its temporal characteristic is obtained as it is shown in Figure 2. In general, we can distinguish m time points of interest from the point of view of the problem under consideration. They can be time points when the objects are examined, observed, tested, measured, etc. As it is described later, $m = 3$ in our considered problem.

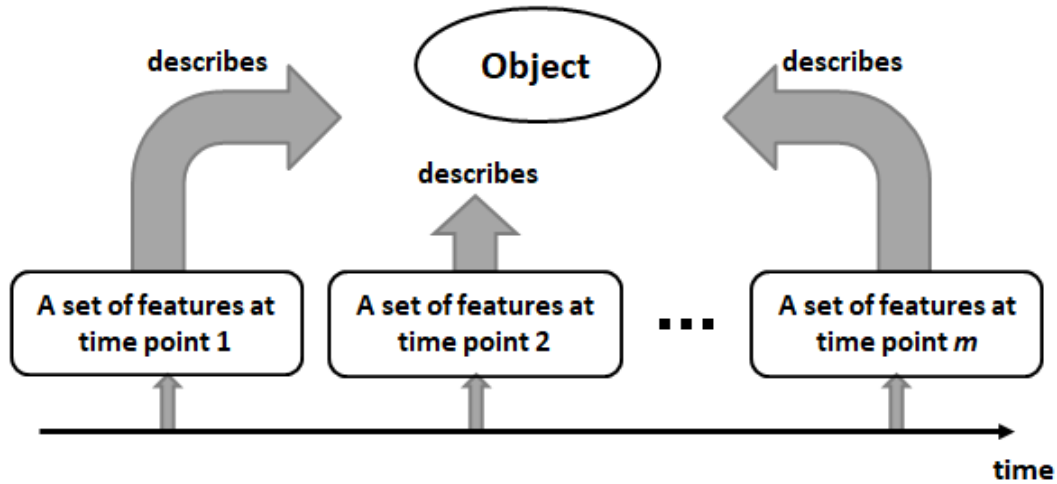


Figure 2. Temporal characteristic of a given object (general).

At each selected time point in a time space, we describe the object by a fixed set of features. It is not necessary for an object to be described by the same sets of features at each time point, i.e., the sets of features can differ both qualitatively and quantitatively. For example, in medical domain, different sets of examinations may be performed or different states may be identified in different situations (e.g., preliminary examinations, check-ups) for a given patient. Sometimes, the check-ups can be more thorough, sometimes less. This can be due to established procedures, capabilities, etc.

Generally, the sets of features considered for objects can be either identical, partly overlapping, or entirely different. The approach presented by us is independent of a particular

situation and it can be used in any of those situations. This is due to the fact that the clustering procedure is made separately over each feature space defined at a given time point. It is worth noting that, at the feature space level, we cannot treat our approach in terms of time series analysis. A time series concerns the same quantities changing in time.

In our approach, we have selected three time points:

1. Before the thermoablation procedure (at this time point, 91 selected features describe patients).
2. 3 months after the thermoablation procedure (at this time point, 29 selected features describe patients).
3. 6 months after the thermoablation procedure (at this time point, 25 selected features describe patients).

Moreover, the fourth time point has been added. It can be identified as evaluation of the cure rate. The attribute corresponding to this time point is a decision attribute (i.e., d in a decision system definition). Therefore, we are dealing formally with a decision system as it was defined earlier. A fragment of a temporal information system (including 7 patients) created for the considered data set is shown in Table 1.

Table 1. A fragment of a temporal information system presented in a tabular form.

<i>Attribute a_1</i>	<i>Attribute a_2</i>	<i>Attribute a_3</i>	<i>Decision attribute (d)</i>
2	4	2	<i>high</i>
1	4	2	<i>medium</i>
1	7	1	<i>low</i>
2	1	3	<i>medium</i>
2	4	2	<i>low</i>
1	2	3	<i>medium</i>
5	7	3	<i>medium</i>

Attributes a_1 , a_2 , and a_3 correspond to the three time points, which were mentioned earlier, respectively. Values of these attributes are cluster identifiers extracted on the basis of proper feature spaces describing patients. Attribute d is a decision attribute. For this attribute, a simple interval clustering has been performed and three clusters marked with low, medium and high cure rate, respectively, have been determined. The cuts for determining intervals were as follows: 0.36 and 0.63. These cuts divided the whole range of values of the decision attribute (that is from 0.0 to 1.0) into three intervals corresponding to linguistic labels: low, medium, and high, respectively. For example, the meaning of the first row is as follows. The object (patient), considered in this row, has been assigned by the clustering procedures to the following clusters: 2 (at time point 1), 4 (at time point 2), 2 (at time point 3), and *high* (for decision).

It is worth noting that, at the cluster space level (as, for example, shown in Table 1), we cannot perceive our approach in terms of time series analysis. In this case, we are not dealing with the same quantities varying over time. Each cluster space can be determined over a different feature space. Therefore, the domains (the sets of values) of attributes in a temporal information system cannot be equated with each other.

One can see that, in general, we can assign a linguistic description to each cluster identifier, which is important, for example, from the point of view of medical diagnosis.

Any sequence $\langle v_1, v_2, \dots, v_k \rangle$, where $v_1 \in V_{a_j}$, $v_2 \in V_{a_{j+1}}$, ..., $v_k \in V_{a_{j+k-1}}$, $j = 1, 2, \dots, m$, and $j + k - 1 \leq m$, is called an episode (over the sets of values of attributes) in a temporal information system $IS = (U, A, \{V_a\}_{a \in A}, f)$. Two episodes $\langle v_1, v_2, \dots, v_k \rangle$ and $\langle v'_1, v'_2, \dots, v'_k \rangle$ are adjacent if and only if either $v_1 = v'_k$ or $v_k = v'_1$. In our approach, episodes are defined over sets of clusters. Basically, one episode is a sequence of cluster identifiers (see Figure 3).

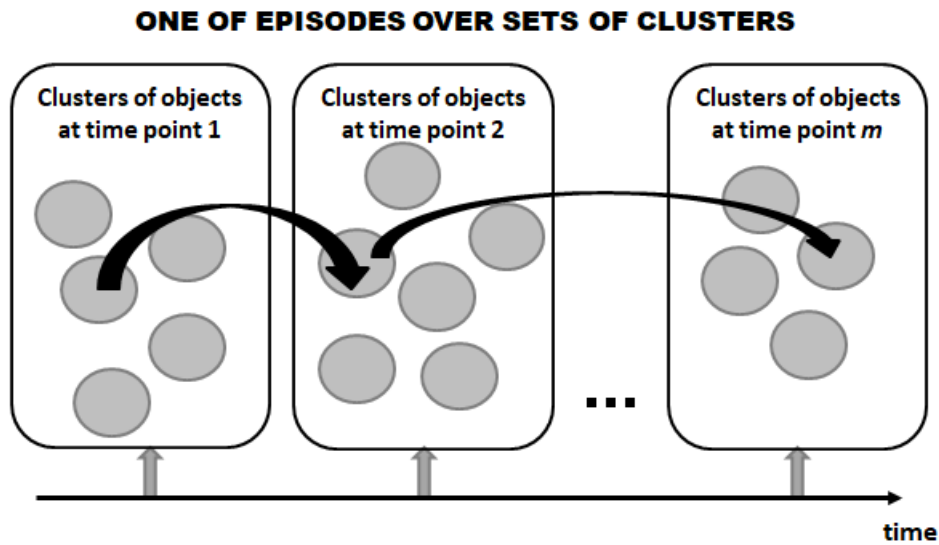


Figure 3. An episode defined over sets of clusters.

In Figure 4, a general scheme of the proposed procedure to build a flow graph and extract episodes is shown. As a result of the procedure, we obtain the episodes, which can be used to make temporal inference about characteristics of objects. In the first step, we determine sets of clusters of objects. The clusters are extracted with respect to feature spaces defined at selected time points. In this step, the ant-based clustering algorithm can be used as it was described in the previous section. As a result of this step, we obtain an information about cluster identifiers to which objects have been assigned in each feature space selected for a given time point. This information is arranged as a temporal information system defined earlier. On the basis of this system, the so-called rough set flow graph is built. Figure 5 shows the proposed procedure applied to data taken into consideration by us.

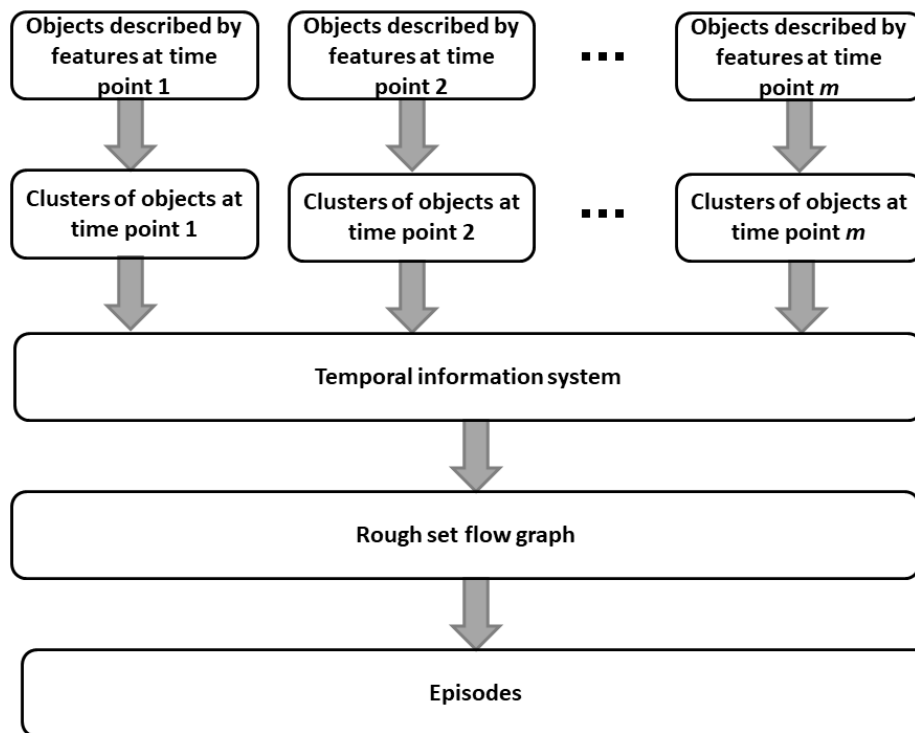


Figure 4. A general scheme of the proposed procedure to build a flow graph.

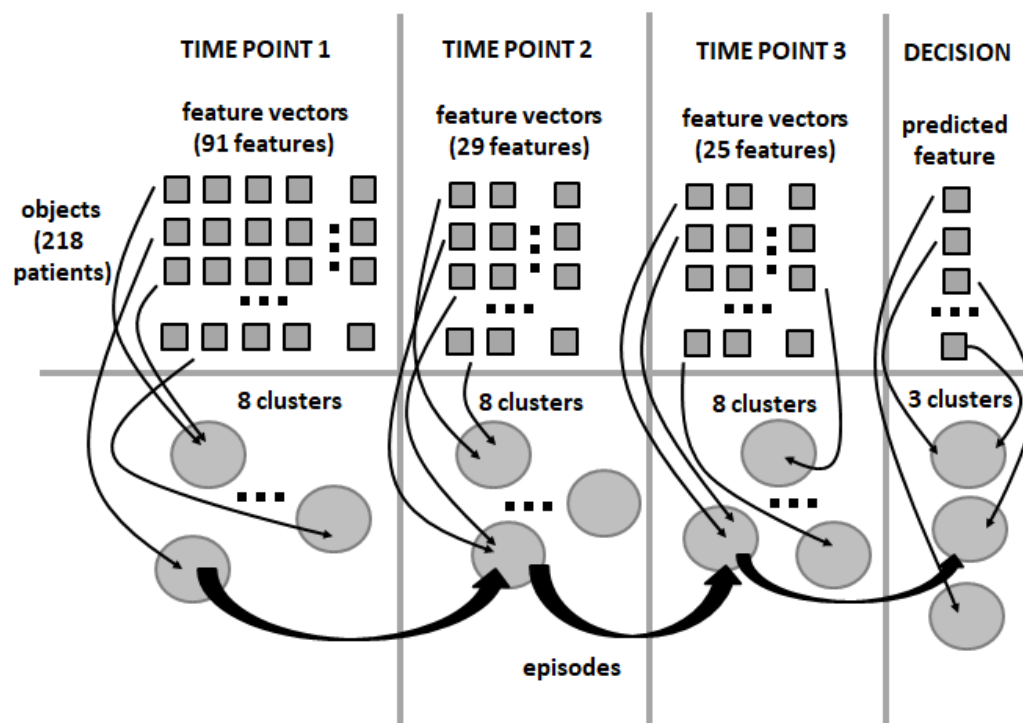


Figure 5. The procedure applied to data taken into consideration.

Information flow distribution is the kind of knowledge that can be helpful in solving different problems appearing in data analysis, especially, if we deal with temporal data, i.e., results of observations or measurements are ordered in time, (cf. (Pancerz, Lewicki, Tadeusiewicz, & Warchol, 2013)). In the literature, different approaches based on flow graphs were proposed. The fundamental one, called flow networks, was proposed by L.R. Ford and D.R. Fulkerson (Ford & Fulkerson, 1962).

Rough set flow graphs were defined by Z. Pawlak (Pawlak, 2005) as a tool for reasoning from data. Let $IS = (U, A, \{V_a\}_{a \in A}, f)$ be a temporal information system with $A = \{a_t: t = 1, 2, \dots, m\}$. A rough set flow graph corresponding to IS is a tuple:

$$RSFG(IS) = \{N, B, cer, str, cov\},$$

where:

- $N = N_{a_1} \cup N_{a_2} \cup \dots \cup N_{a_t}$ is the set of nodes such that for each $a \in A$: $card(N_a) = card(V_a)$, i.e., each node in N_a corresponds exactly to one attribute value from V_a ,

- $B \subseteq N \times N$ is the set of multi-labelled directed branches, where each branch $(n, n') \in B$, where $n \in N_{a_{i-1}}$, $n' \in N_{a_i}$, and $i = 2, 3, \dots, t$, is labelled with three values:

$$\begin{aligned} \circ cer(n, n') &= \frac{card(\{u \in U: f(a_{i-1}, u) = v \wedge f(a_i, u) = v'\})}{card(\{u \in U: f(a_{i-1}, u) = v\})}, \\ \circ cov(n, n') &= \frac{card(\{u \in U: f(a_{i-1}, u) = v \wedge f(a_i, u) = v'\})}{card(\{u \in U: f(a_i, u) = v'\})}, \\ \circ str(n, n') &= \frac{card(\{u \in U: f(a_{i-1}, u) = v \wedge f(a_i, u) = v'\})}{card(U)}, \end{aligned}$$

such that n corresponds to $v \in V_{a_{i-1}}$ and n' corresponds to $v' \in V_{a_i}$.

These three values $cer(n, n')$, $cov(n, n')$, and $str(n, n')$ are called certainty, coverage, and strength of the branch (n, n') , respectively. One can see that $cer(n, n') \in [0, 1]$, $cov(n, n') \in [0, 1]$, and $str(n, n') \in [0, 1]$ for each n and n' . These coefficients assigned to each branch play an important role in reasoning from data. One can see that formulas determining certainty and covering refer to Bayes' rules. Hence, rough set flow graphs can be used as an interesting tool to perform reasoning processes.

The algorithm for creating a temporal rough set flow graph corresponding to a temporal information system can be described as follows:

1. At the beginning, an empty set N of nodes and an empty set B of directed branches are created.
2. For each attribute a in the set A of attributes of a temporal information system, for each value v of a , the node corresponding to v is created and added to N .
3. For each pair of nodes corresponding to values of adjacent attributes in a temporal information system, a branch linking these nodes is created and added to B .
4. For each branch, three labels associated with it are calculated on the basis of formulas given earlier (see definitions of certainty, coverage, and strength).

It is worth noting that, in case of a rough set flow graph built on the basis of a temporal information system, each layer of nodes in the graph corresponds to values of attributes determined for a given time point.

The rough set flow graph obtained for the considered data set is shown in Figure 6 (this graph is extracted from a fragment of a temporal information system shown in Table 1). Each

horizontal layer includes nodes corresponding to clusters obtained for a given time point. Each node is marked with the attribute name and the cluster identifier. Each branch is described by three coefficients: certainty (*cer*), coverage (*cov*), and strength (*str*) mentioned earlier.

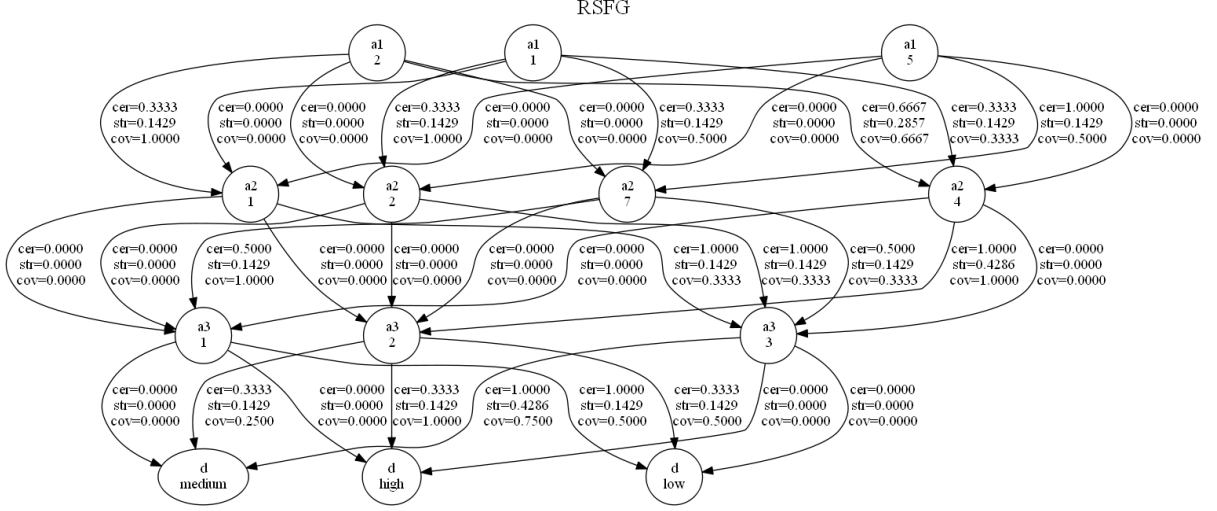


Figure 6. A fragment of the rough set flow graph.

The final goal of the presented approach is to find significant episodes over the sets of clusters. Discovering such episodes can be made by the approach using the ant-based clustering algorithm as it was shown in (Lewicki & Pancerz 2020). The main goal of the ants is to carry episodes and concatenate them into longer episodes. We can say that the longer the episode, the more information it gives to us. The longer episode represents the longer path of possible states of objects in consecutive time points.

The ant-based algorithm can be described as follows.

1. At the beginning, the episodes, each consisting of one cluster, are created.
2. A given ant picks up randomly one of the episodes and carries it.
3. An episode can be dropped by the ant next to another episode if these episodes are adjacent. Then a new episode is created by concatenating these two episodes together. The probability of concatenation depends on the certainty of the new episode.

It is worth noting that to determine the certainty of the new episode created during the clustering procedure, we can use a special class of functions, called triangular norms (known especially from fuzzy set theory) due to the fact that $cer(n, n') \in [0, 1]$ for any nodes n and n' . Triangular norms can be either t-norms or t-conorms (see (Klement, Mesiar & Pap, 2000)). In general, the certainty of the new episode e is a triangular norm T of the certainties of the concatenated episodes e' and e'' , i.e.:

$$cer(e) = T(cer(e'), cer(e'')).$$

Moreover, we can use strength or coverage coefficients instead of a certainty coefficient. The rough set flow graph from Figure 6 with a distinguished episode is shown in Figure 7.

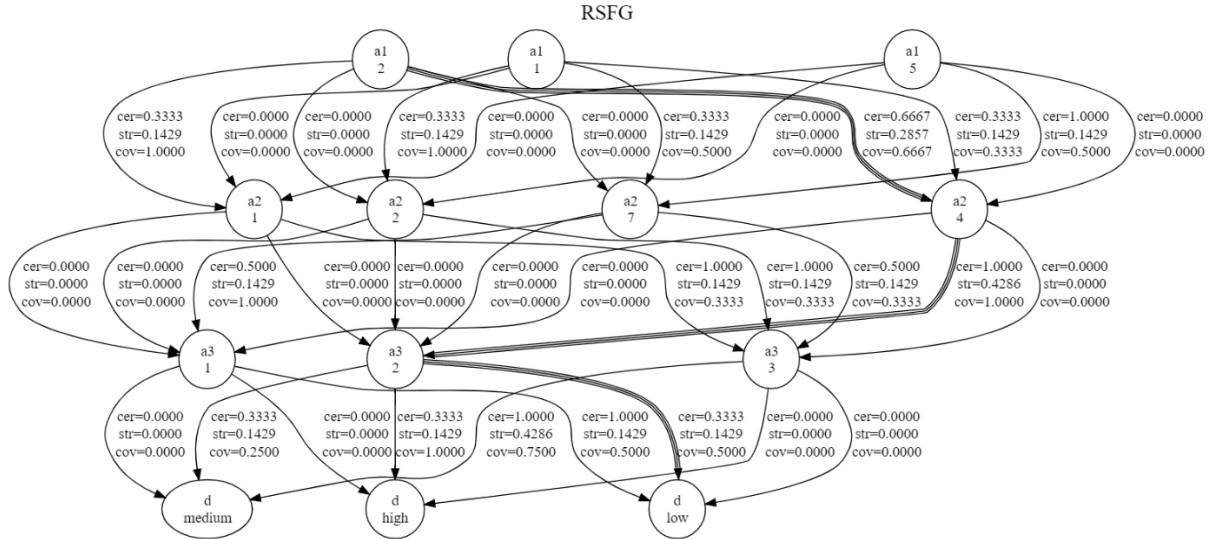


Figure 7. A fragment of the rough set flow graph with a distinguished episode.

The fragment of the set of episodes extracted by means of the ant-based algorithm (in which a minimum t-norm was used to determine certainties of created episodes during the clustering procedure) is as follows:

a2=3 -> a3=6 -> d=high
 a3=4 -> d=high
 a2=7 -> a3=7 -> d=medium
 a1=1 -> a2=1 -> a3=3 -> d=medium
 a3=5 -> d=high
 a3=0 -> d=high
 a1=4 -> a2=2 -> a3=2 -> d=low
 a2=2 -> a3=1 -> d=medium
 a1=2 -> a2=1 -> a3=3 -> d=medium
 a1=0 -> a2=0 -> a3=7 -> d=medium
 a1=4 -> a2=2 -> a3=2 -> d=medium
 a2=4 -> a3=2 -> d=medium
 a1=7 -> a2=6 -> a3=3 -> d=medium
 a1=4 -> a2=2 -> a3=3 -> d=medium
 a1=5 -> a2=5 -> a3=3 -> d=medium

Let us consider episode:

a2=4 -> a3=2 -> d=medium

In the considered data set, this episode is supported by the patients included in Table 2. Having this information, we can move to description of clusters: 4 (at time point 2) and 2 (at time point 3) and analyse values of features taken into consideration in these time points.

Table 2. A fragment of a temporal information system including patients supporting episode $a_2=4 \rightarrow a_3=2$
 $\rightarrow d=\text{medium}$

<i>Attribute a_1</i>	<i>Attribute a_2</i>	<i>Attribute a_3</i>	<i>Decision attribute (d)</i>
1	4	2	medium
1	4	2	medium
5	4	2	medium
2	4	2	medium
2	4	2	medium

The effectiveness of the algorithm was validated using the ten-fold cross validation approach. In each iteration, nine parts were used in the training stage to create a rough set flow graph and to generate significant episodes using the ant-based clustering. One part was used to determine actual certainties of the episodes found in the training stage. Next, we calculated: the average value of actual certainties of the episodes, the average value and the standard deviation for differences between the actual certainties of the episodes and the predicted certainties (determined in the training step) of the episodes.

The presented algorithm has the polynomial time complexity. One can see that the brute force search of the entire space of episodes leads to the exponential time complexity on account of a number of attributes in a given temporal information system.

The extracted episodes can be used in reasoning processes. Each episode can be seen as rules delivering information flow between particular layers corresponding to time points in a given time space. In contrast to the classical classification problem, the presented approach makes it possible to gain information about the possible successions of states between stages defined in a given time space. Such successions of states are expressed by episodes. Therefore, not only reasoning on final decisions is possible. The local temporal inference is also available.

Software Tool

Creation of rough set flow graphs and extraction of episodes using the ant-based clustering algorithm have been implemented in our software tool called Classification and Prediction Software System (CLAPSS), see (Pancerz, Lewicki & Sarzynski, 2019). It is a tool developed for solving different classification and prediction problems using, among others, some specialized approaches based mainly on fuzzy sets and rough sets. The tool is equipped with a graphical interface (see Figure 8). The ant-based clustering procedure for extracting episodes can be parametrized by the user as it is shown in Figure 9. The user can set the number of ants and the number of iterations. Moreover, one can select one of the triangular norms from the sets of the most known t-norms and t-conorms (minimum/maximum, algebraic/probabilistic product, Lukasiewicz, Einstein, Hamacher, Fodor, drastic).

The temporal inference with the use of ant-based clustering algorithm and flow graphs in the problem of prognosing complications of medical surgical procedures

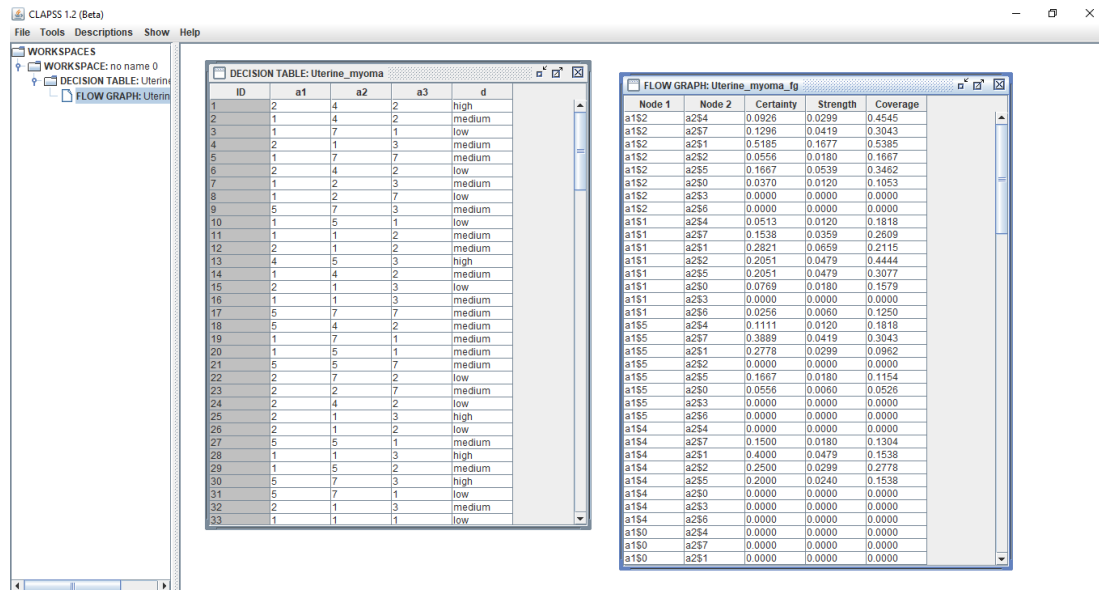


Figure 8. The GUI of CLAPSS.

Figure 9 shows the 'Ant-Based Extraction' dialog box. It contains the following parameters:

- Number of ants:** 12
- Number of iterations:** 10,000
- Selection:**
 - ☒ T-norms
 - ☐ S-norms
- T-norm for episode certainties:** minimum
- S-norm for episode certainties:** probabilistic sum
- Buttons:** OK, Cancel

Figure 9. Parametrization of the ant-based clustering procedure for extracting episodes.

An information or decision system (particularly, a temporal information system) can be loaded into CLAPSS from files recorded in several formats. The tool accepts popular text formats of data tables used in other data mining and machine learning tools, i.e., WEKA (Hall et al., 2009), RSES (Bazan & Szczuka, 2005) and the XML format used in ROSETTA (Ohrn, Komorowski, Skowron & Synak, 1998). CLAPSS enables the user to export the created rough set flow graph to the DOT format used in the Graphviz tool (Ellson, Gansner, Koutsoos, North & Woodhull, 2004) as well as to the PNG format. Inputs and outputs in CLAPSS are shown in Figure 9. One can see interoperability of CLAPSS with other software tools.

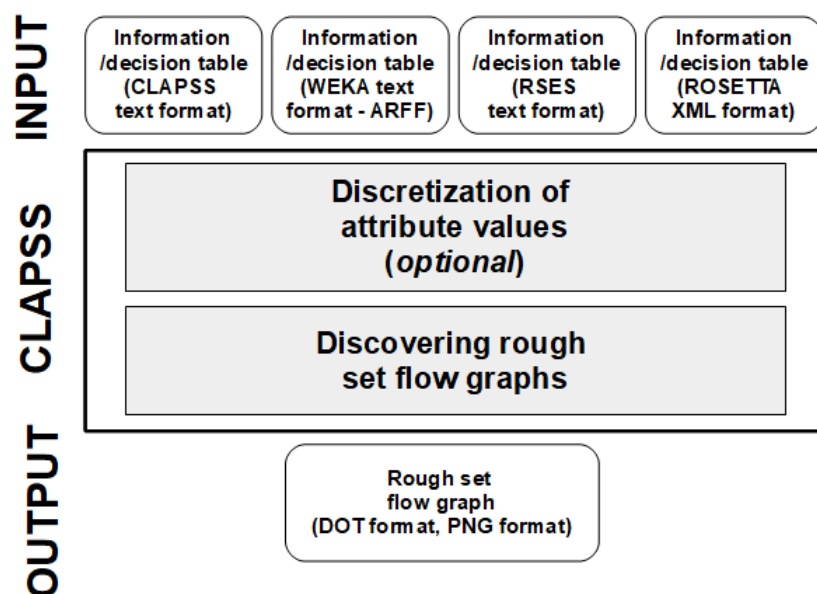


Figure 10. Inputs and outputs in CLAPSS.

The fragment of a temporal information system presented in Table 1, recorded in the internal CLAPSS format, looks like this:

```
TABLE Uterine_myoma
a1 a2 a3 d
integer integer integer string
condition condition condition condition
2 4 2 high
1 4 2 medium
1 7 1 low
2 1 3 medium
2 4 2 low
1 2 3 medium
5 7 3 medium
```

DISCUSSION AND CONCLUSIONS

Many classical medical decision problems are reduced to classification problems based on sets of feature vectors describing patients. In the paper, we have shown the approach based on temporal information about patients. Results of diagnostics during the treatment process (multi-stage in many cases) can be used to model temporal information flow and to perform temporal inference. It is possible due to separation of features determined at different stages of treatment.

Moreover, many classical medical decision problems are focused on the construction of the most accurate classifiers or classifier ensembles. In this case, the main goal is to obtain the

best quality of the classification of patients. Accurate classification is a significant problem, but other important issues considered in medical diagnosis are: explanation of decisions made for new patients and imitation of human diagnostic procedures by computer tools. Then, solving a classification problem is not the only goal. The diagnosticians also strive to understand, among other things, the structure of the decision problem, interdependencies between particular stages of treatment, etc. As it has been presented in the paper, extracted episodes have a human readable form that can be used in reasoning processes. Our software tool (CLAPSS) enables the users to analyse medical decision problems. The models in the form of rough set flow graphs, as well as extracted episodes, enrich the problem analysis, and ultimately the diagnosis.

In our approach, we have used the ant-based clustering algorithms which are capable of dealing with the data with a poorly known structure. It is important in case of dozens of features describing patients. As the example, the problem of the thermoablation procedure in treatment of uterine myoma disease has been considered. However, in the paper, we have shown a general scheme for the modelling of the decision problems in case of multistage treatments. The presented approach fits into the general problems considered in data mining called sequence mining or temporal data mining (cf. Dong & Pei, 2007; Mitsa, 2010).

The presented approach differs from the approaches to discovering frequent episodes. We can indicate the following significant differences:

1. The frequent episodes are considered as collections of events that occur relatively close to each other in a given partial order (cf. (Mannila, Toivonen & Verkamo, 1997)). Particularly, serial and parallel episodes are considered. In our approach, we consider only ordered sets of attribute values describing objects of interest.
2. Our approach is focused on certainties of sequences, not on their frequencies of occurrence. In our approach, we are interested in information flow between elements of episodes (coefficients associated with branches, linking nodes in rough set flow graphs). If the frequencies of occurrence are considered, the coexistence of elements in episodes is taken into account.

The presented approach differs also from the approaches to clustering episodes. Classical clustering procedures implement the so-called vertical clustering (episodes are clustered to build groups of episodes). In our approach, a clustering procedure implements the so-called horizontal clustering. Shorter pieces of episodes (starting with one-element episodes) are concatenated to build longer ones (according to given criteria).

One of our directions for further research is to apply fuzzy flow graphs to the considered and other medical decision problems. Creation of fuzzy flow graphs and extraction of episodes using the ant-based clustering algorithm have been also implemented in our software tool (CLAPSS), see (Pancerz, Lewicki & Sarzynski, 2019). Moreover, an important issue is to use a domain knowledge to improve solving decision problems (see for example (Bazan, Buregwa-Czuma & Jankowski, 2013)). The domain knowledge can have different forms. One of them has the form of ontologies. Linking ontologies with attribute values in temporal information systems was considered in (Pancerz, 2016).

REFERENCES

- Alnoukari, M., & El Sheikh, A. (2012). Knowledge discovery process models: from traditional to agile modeling. In *Business Intelligence and Agile Methodologies for Knowledge-Based Organizations: Cross-Disciplinary Applications* (pp. 72-100). IGI Global.
- Bazan, J. G., Buregwa-Czuma, S., & Jankowski, A. W. (2013). A domain knowledge as a tool for improving classifiers. *Fundamenta Informaticae*, 127(1-4), 495-511.
- Bazan, J. G., & Szczuka, M. (2005). The rough set exploration system. In *Transactions on Rough Sets III* (pp. 37-56). Springer, Berlin, Heidelberg.
- Boryczka, U. (2008). Ant clustering algorithm: Intelligent information systems. Kluwer Academic Publishers.
- Burney, A., & Abbas, Z. (2015). Applications of rough sets in health sciences and disease diagnosis. *Recent Researches in Applied Computer Science*, 8(3), 153-161.
- Daneshjou, R., Smith, M. P., Sun, M. D., Rotemberg, V., & Zou, J. (2021). Lack of Transparency and Potential Bias in Artificial Intelligence Data Sets and Algorithms: A Scoping Review. *JAMA dermatology*, 157(11), 1362-1369.
- De La Cruz, M. S. D., & Buchanan, E. M. (2017). Uterine fibroids: diagnosis and treatment. *American family physician*, 95(2), 100-107.
- Deneubourg, J. L., Goss, S., Franks, N., Sendova-Franks, A., Detrain, C., & Chrétien, L. (1991, February). The dynamics of collective sorting robot-like ants and ant-like robots. In *From animals to animats: proceedings of the first international conference on simulation of adaptive behavior* (pp. 356-365).
- Dhillon, A., & Singh, A. (2019). Machine learning in healthcare data analysis: a survey. *Journal of Biology and Today's World*, 8(6), 1-10.
- Dong, G., & Pei, J. (2007). *Sequence data mining* (Vol. 33). Springer Science & Business Media.
- Ellson, J., Gansner, E. R., Koutsofios, E., North, S. C., & Woodhull, G. (2004). Graphviz and dynagraph—static and dynamic graph drawing tools. In *Graph drawing software* (pp. 127-148). Springer, Berlin, Heidelberg.
- Ford, L. R., & Fulkerson, D. R. (2015). *Flows in networks*. Princeton university press.
- Hall, M., Frank, E., Holmes, G., Pfahringer, B., Reutemann, P., & Witten, I. H. (2009). The WEKA data mining software: an update. *ACM SIGKDD explorations newsletter*, 11(1), 10-18.
- Handl, J., Knowles, J. D., & Dorigo, M. (2003). On the Performance of Ant-based Clustering. *HIS*, 105, 204-213.
- Kalamarz, P., Zagrobelna, M., & Pyziak, L. (2017). Focusing ultrasounds beam. *Physics for Economy*, 1, 15-26.
- Klement, E. P., Mesiar, R., & Pap, E. (2000). Families of t-norms. In *Triangular Norms* (pp. 101-119). Springer, Dordrecht.
- Lewicki, A., & Pancerz, K. (2020). Ant-based clustering for flow graph mining. *International Journal of Applied Mathematics and Computer Science*, 30(3), 561-572.
- Lozinski, T., Filipowska, J., Pyka, M., Baczkowska, M., & Ciebiera, M. (2021). Magnetic resonance-guided high-intensity ultrasound (MR-HIFU) in the treatment of symptomatic uterine fibroids—five-year experience. *Ginekologia Polska*. doi: 10.5603/GP.a2021.0098.
- Lumer, E. D., & Faieta, B. (1994, July). Diversity and adaptation in populations of clustering ants. In *Proceedings of the third international conference on Simulation of adaptive behavior: from animals to animats 3: from animals to animats 3* (pp. 501-508).
- Mannila, H., Toivonen, H., & Verkamo, A. I. (1997). Discovery of frequent episodes in event sequences. *Data mining and knowledge discovery*, 1(3), 259-289.

- Mitsa, T. (2010). *Temporal data mining*. CRC Press.
- Øhrn, A., Komorowski, J., Skowron, A., & Synak, P. (1998). The ROSETTA software system. *Rough Sets in Knowledge Discovery*, 2, 572-576.
- Pancerz, K. (2016). Paradigmatic and syntagmatic relations in information systems over ontological graphs. *Fundamenta Informaticae*, 148(1-2), 229-242.
- Pancerz, K., Lewicki, A., & Tadeusiewicz, R. (2012, July). Ant based clustering of two-class sets with well categorized objects. In *International Conference on Information Processing and Management of Uncertainty in Knowledge-Based Systems* (pp. 241-250). Springer, Berlin, Heidelberg.
- Pancerz, K., Lewicki, A., Tadeusiewicz, R., & Warchoń, J. (2013). Ant-based clustering in delta episode information systems based on temporal rough set flow graphs. *Fundamenta Informaticae*, 128(1-2), 143-158.
- Pancerz, K., Lewicki, A., & Sarzyński, J. (2019, June). Discovering Flow Graphs from Data Tables Using the Classification and Prediction Software System (CLAPSS). In *International Joint Conference on Rough Sets* (pp. 356-368). Springer, Cham.
- Pawlak, Z. (1991). *Rough sets: Theoretical aspects of reasoning about data* (Vol. 9). Springer Science & Business Media.
- Pawlak, Z. (2005). Flow graphs and data mining. In *Transactions on rough sets III* (pp. 1-36). Springer, Berlin, Heidelberg.
- Pawlak, Z. (2005, August). Rough sets and flow graphs. In *International Workshop on Rough Sets, Fuzzy Sets, Data Mining, and Granular-Soft Computing* (pp. 1-11). Springer, Berlin, Heidelberg.
- Pawlowski, C. (2019). *Machine learning for problems with missing and uncertain data with applications to personalized medicine* (Doctoral dissertation, Massachusetts Institute of Technology).
- Ren, S., Lu, X., & Wang, T. (2018, March). Application of ontology in medical heterogeneous data integration. In *2018 IEEE 3rd International Conference on Big Data Analysis (ICBDA)* (pp. 150-155). IEEE.
- Sainio, T., Saunavaara, J., Komar, G., Mattila, S., Otonkoski, S., Joronen, K., ... & Blanco Sequeiros, R. (2021). Feasibility of apparent diffusion coefficient in predicting the technical outcome of MR-guided high-intensity focused ultrasound treatment of uterine fibroids—a comparison with the Funaki classification. *International Journal of Hyperthermia*, 38(1), 85-94.
- Salcedo-Bernal, A., Villamil-Giraldo, M. P., & Moreno-Barbosa, A. D. (2016). Clinical data analysis: An opportunity to compare machine learning methods. *Procedia Computer Science*, 100, 731-738.
- Singh, S., & Srivastava, S. (2020). Review of Clustering Techniques in Control System: Review of Clustering Techniques in Control System. *Procedia Computer Science*, 173, 272-280.
- Su, T., & Dy, J. G. (2007). In search of deterministic methods for initializing K-means and Gaussian mixture clustering. *Intelligent Data Analysis*, 11(4), 319-338.
- Thirumahal, R., & Sadasivam, G. (2020). Data integration techniques for healthcare – a comprehensive survey. *International Journal of Computer Sciences and Engineering Open Access*.
- Tripathi, S., Muhr, D., Brunner, M., Jodlbauer, H., Dehmer, M., & Emmert-Streib, F. (2021). Ensuring the robustness and reliability of data-driven knowledge discovery models in production and manufacturing. *Frontiers in Artificial Intelligence*, 4, 22.
- Verpalen, I. M., Anneveldt, K. J., Nijholt, I. M., Schutte, J. M., Dijkstra, J. R., Franx, A., ... & Boomsma, M. F. (2019). Magnetic resonance-high intensity focused ultrasound (MR-HIFU) therapy of symptomatic uterine fibroids with unrestrictive treatment protocols: A systematic review and meta-analysis. *European journal of radiology*, 120, 108700. doi: 10.1016/j.ejrad.2019.108700.

- Vlamou, E., & Papadopoulos, B. (2019). Fuzzy logic systems and medical applications. *AIMS neuroscience*, 6(4), 266.
- Wen, D., Khan, S. M., Xu, A. J., Ibrahim, H., Smith, L., Caballero, J., ... & Matin, R. N. (2021). Characteristics of publicly available skin cancer image datasets: a systematic review. *The Lancet Digital Health*.

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Human Technology
ISSN 1795-6889
<https://ht.csr-pub.eu>

ADDED VALUE OF MOTION CAPTURE TECHNOLOGY FOR OCCUPATIONAL HEALTH AND SAFETY INNOVATIONS

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Abstract: *Ergonomic principles in production assembly and manufacturing operations have become an essential part of comprehensive health and safety innovations. We aim to provide new insights into occupational health and safety innovations and how they utilise biomechanical methods and cutting-edge motion capture technology by assessing movements at a workplace. The practical goal is to quantify a connection between work exposure and ergonomic risk measures to determine biomechanical risk factors of diseases or health-related disorders objectively. The target group consisted of 62 factory employees working in manufacturing (26 participants on 12 devices) or assembly areas (36 participants on 9 devices). Body posture, body parts position, movements, energy cost and workloads were assessed using an inertial motion capture (MC) system. MC technology accurately assesses the operator's movements. The proposed methodology could complement ergonomic procedures in the design of workstations, which is the added value of the motion capture technology for occupational health and safety innovations.*

Keywords: *computer technology, motion capture, risk assessment, ergonomics, mobility, musculoskeletal disorders.*



INTRODUCTION

Occupational health and safety interventions using a great variety of technologies (like VR, AI and bots) are becoming more and more valid. They are being used by many manufacturing corporations to protect workers against accidents, minimising as well as eliminating monotony, repetitive tasks, and working with heavy loads (Zhang et al., 2021). Nonetheless, the European Agency for Safety and Health at Work (EU-OSHA), the International Labour Organisation, and the WHO have been calling for a reduction in the increasing number of occupational health problems and new psychosocial risks in recent years. According to ESENER-3¹, the most frequently identified risk factors are repetitive work, dealing with demanding customers, and lifting or moving heavy loads. Moreover, the results of research conducted and reported by EU-OSHA (2019) have shown that the physical, organisational, and psychosocial factors contribute to the development of many work-related health problems faced by workers. Currently, the rising problems pertain to work-related musculoskeletal disorders (WRMSDs). WRMSDs concern workers in all sectors and occupations. Not only do they have a negative effect, but they also lead to high costs for businesses and society in general. Of all workers with a work-related health problem in the EU, 60% identify WRMSDs as their most serious issue². Various examples of WRMSDs are diagnosed among employees: upper limb, lower limb, and back WRMSDs. The most common types of WRMSDs reported by workers are backache and muscular pains in the shoulders, neck, and upper limbs; muscular pains in the lower limbs are reported less often. Bearing in mind the multifactorial nature of WRMSDs, it is crucial to skilfully plan and conduct health and safety (H&S) interventions. Firstly, they should be holistic, integrated, and based on preventive and protective measures (e.g., the provision of ergonomic equipment, encouragement of regular breaks for people in uncomfortable working positions, and rotation of tasks to reduce repetitive movements). At this point, it is worth paying attention to the growing role of using technology in this area.

Besides, a prolonged standing position with the trunk motionless for an extended period may increase intervertebral stress (Gallagher & Callaghan, 2015) as well as thoracic and lumbar intradiscal pressure (Liebsch & Wilke, 2021; Polga et al., 2004). Moreover, this posture has been associated with the idiopathic viscoelastic deformation of lumbar tissues (Solomonow et al., 2003). Alterations in spinal curves may also affect the development of lower back pain (Oakley et al., 2005; O'Sullivan et al., 2017). Measurement of the fluid pressure in the intradiscal cavity shows the level of pressure changes during different daily life or working postures. It has been revealed, standing posture (with inclined trunk) may produce relatively higher disk pressures (by around 50%) than a seated upright posture, attributing to the fact that the line of gravity for the upper body acts farther away from the instantaneous centre of rotation. Several other vital applications of biomechanical analysis may be named. The lifting guidelines suggested by the National Institute of Occupational Safety and Health (NIOSH) employ the biomechanical criteria of a maximum acceptable compressive loading on the vertebral unit in setting the maximum load that an individual can safely lift. This recommendation includes some physiological and biomechanical factors for evaluating loading of the human body grounded on the physical limitations as a result of the strength or posture of the body (Barim et al., 2019; Fox et al., 2019; Waters et al., 1993). These involve: the variability in size and shape of the human body, the variability in types and range of movements, the mass and shape of handling object, frequency of lifting (repetitive hand or arm

movements increases both the dynamic joint loading and the metabolic energy cost), forward and upward reach (static loading, increased LBP risk), working at very high speed, carrying or moving heavy loads, control at the endpoint of the loading, asymmetry of lifting, coupling of the load, etc. Other safety guidelines are found in designing different types of equipment, tools, or workstations to utilise the midrange of motion of body segments optimally. Existing WRMDs databases have documented the maximum forces that can be applied at various limb positions and body postures. These databases may be used to manage or supervise the amount of work output depending on the worker's posture without inflicting any form of harmful musculoskeletal loading. For example, the maximal two-handed mass /weight that can be transported repetitively by a male in a standing position is 10 kg (for the low-risk category, OCRA Index of 1) or 20 kg (for the high-risk category, OCRA Index of 3) (EN 1005-5, ISO 11228-3) but also depends on the frequency of repetitions (from 0 to 15 lifts per minute according to ISO 11228-1). High forces are associated with lifting relatively heavy objects to high levels, while the weight of the handled objects is often the main predictor of high loads and musculoskeletal forces (Skals et al., 2021). Any job requiring an individual to perform such a task should be designed in conformity with this criterion for avoiding worker discomfort and the possibility of WRMDs or injury. Such databases are limited in population size and scope and need to be expanded to include the specific working population or movement tasks under consideration (Karwowski & Marras, 2003).

In addition, several studies have found a relationship between spinal curves and ventilatory responses. A systematic study comparing lumbopelvic kinematics in people with and without low back pain (LBP) revealed no difference from asymptomatic people concerning the angle of lumbar lordosis or the angle of the anterior tilt of the pelvis in a standing position. However, people did show differentiation in terms of the lumbar spine's range of motion in all directions, its velocity, and worsened proprioception during movement relocation (Laird et al., 2014). There is also strong evidence that the size of motor variability in a healthy subject affects the prognosis for contracting pain and fuels the idea in occupational health that movement variation decreases the risk of developing MSDs (Srinivasan & Mathiassen, 2012). If movements are repeated more similarly, it would be more likely that the same soft tissues receive large doses of exposure. Increased movement and posture variability would thus modify tissue loads from repetition to repetition, distribute stresses more equally among tissues, and thus reduce the cumulative load on any particular tissue (Srinivasan & Mathiassen, 2012). The idea that a significant motor variability may have a protective role in preventing chronic MSDs has been proposed by Mathiassen, Burdorf, et al. (2003); Mathiassen, Möller, et al. (2003) and supported by Côté (2012), Madeleine, Mathiassen, et al. (2008) and Madeleine, Voigt, et al. (2008). Some researchers also indicate a strong link between WRMSDs (mainly LBP) and the task or movement asymmetry (Beaucage-Gauvreau et al., 2019; Kim & Zhang, 2017; Mehta et al., 2014). Increases in nonsagittal plane movement (lateral or twist) will usually accompany more asymmetric loads since the weight is located away from the midline of the sagittal plane, causing the individual to twist and bend sideways.

Health and safety (H&S) interventions are divided into three categories, according to their goals: primary—identification of causes and their subsequent elimination or reduction; secondary—supporting employees' ability to cope with the existing overload, teaching them appropriate techniques and skills; tertiary—psychological or medical intervention when the impairment or disease is already appearing (De Angelis et al., 2020; Nielsen & Randall, 2015;

Sinclair et al., 2010). The first goal is achieved through interventions at the organisational level, where more general solutions are implemented. The other two are the interventions focused on improving an individual's functioning, and they are named individual-level interventions (Dalgren & Gard, 2013; Richardson & Rothstein, 2008; Schabracq et al., 2004). Interventions focused on improvements in human work in manufacturing processes are based mainly on ergonomics (Bhattacharya & McGlothlin, 2011), but they are also related to many scientific fields such as physiology, physiotherapy, biophysics, occupational psychology, and occupational health (Karimi et al., 2020; Skals et al., 2021; Taibi et al., 2021). In this study, we want to combine the knowledge from those fields to add the value of motion capture technology into an in-depth analysis of human work. This is why the goal of the present study is to assess workplace movements at machining or assembly workstations, to state protective measures (through observation), and to identify and evaluate risk factors of health-related events (analytic study). A high level of work exposure with a combination of extreme angle values, body part loads, asymmetry of movements, high velocity of arms or extremely low movement variability could pose additional, biomechanical risk factors in work-related musculoskeletal disorders. Which is why we could establish evidence-based recommendations to improve H&S procedures and implement tailored programmes to avoid musculoskeletal problems or impairments.

METHODS

Participants' Inclusion Criteria

All measurements were made in a workplace environment in a plant of an automotive multinational corporation (MNC).

All participants were full-time employees working on the same shift. The variation in job tenure was moderate (0.5–40 years, mean = 12.3). The research included 26 employees (41.9 ± 9.6 years of age, body mass: 79.9 ± 13.6 kg, height: 1.76 ± 0.07 m) working in manufacturing on 12 devices and 36 employees (35.5 ± 9.5 years of age, 69.2 ± 13.3 kg, 1.69 ± 0.10 m) working in assembly areas on nine devices. The inclusion criteria were a minimum experience age of six months at the workstation, maximum age of 60 years, and no history of pain concerning the musculoskeletal system that could influence the range or speed of movements. Manufacturing (MWE) and assembly (AWE) workstations are evaluated against work-related risk factors every three years. During the evaluations, the following “ergochecks” (preliminary mapping of potential risks in workplace environment) are performed: (1) the identification of high-risk factors using the company's tailored risk assessment checklist (2) repetitive movements evaluations (ISO 11228-3 norm and the OCRA method in the risk assessment), (3) carrying, pushing and pulling objects (ISO 11228-1 and ISO 11228-2 norms), (4) lifting loads one-handed (EN 1005-2 norm) and two-handed (NIOSH norm). The company uses internal norms for all factory units. Mainly, they refer to load evaluation of hand, arm and fingers. According to the company's Health and Safety management and quality auditors, the MWE and AWE workstations are of low risk (green zone according to OCRA Index), but still, from the workers perspective, the participants were exposed to risk factors associated with WRMSDs (Bernard, 1997), such as (A) repetitive tasks involving cyclical flexion, extension,

abduction and rotation of joints, (B) static posture, with flexed, abducted and extended arms, (C) strenuous work during production cycles, (D) lifting movements, (E) awkward positions with non-neutral trunk postures, trunk flexion, rotation and torsion. The research project was approved by the company's H&S division and supported by the human resources department. The biomechanical procedure complied with the Declaration of Helsinki regarding human experimentation. The study was also approved by the Rector's Committee for Research Ethics of Wroclaw University of Economics and Business (case no. 33/2020). After receiving all relevant study information, the participants signed informed consent, including permission to publish the data anonymously.

Measurement Set-Up and Procedure

All parameters were registered using an MR3 myoMuscle Master Edition system (myoMOTION™, Noraxon, Scottsdale, AZ, USA). The myoMOTION system consists of a set of 16 inertial motion units (IMUs) using inertial sensor technology. Based on fusion algorithms, the information from an IMU sensor (3D accelerometer, gyroscope, and magnetometer) is transformed to measure the 3D rotation angles (yaw-pitch-roll, also called navigation angles) of each sensor in absolute space. The inertial sensors were located on the body of the study employee to record the accelerations according to the myoMotion protocol described in the instruction manual. Previous research has checked and demonstrated the scientific validity and high accuracy of the IMU system in angle determination (± 0.4 deg. for static and ± 1.2 deg for dynamic analysis) (Bańkosz & Winiarski, 2021; Teufl et al., 2019). It is alleged that inertial motion capture technology is low cost and more portable than markerless optical technology, but the system's accuracy must be assured (Karatsidis et al., 2016; Yunus et al., 2021).

The research strictly followed the International Society of Biomechanics' recommendations on definitions of joint coordinate systems for reporting human joint motion and intersegmental forces and moments during human motion (Derrick et al., 2020; Wu et al., 2002, 2005; Wu & Cavanagh, 1995). Primarily, the inertial motion capture system employed a 16-segmental biomechanical model of the human body, Euler angles for determining the position and orientation of the segments in 3D measurement space, and the medical angles for describing the 3D movement after decomposing into three orthogonal planes of motion. All registrations were carried out in the manufacturing or assembly area of the company. Special care was taken during the acquisition to avoid sources of bias and confounding by eliminating nonworking movements or actions (e.g., stuck components, unplanned breaks, reaching for a bottle of water). No magnetic field interference or cross-talk artefacts from operating equipment were noticed as affecting the recording result.

IMU sensors were attached with elastic straps and self-adhesive tape so that the sensor's y-coordinate corresponded to the frontal horizontal axis and the z-coordinate to the sagittal horizontal axis of the body part (Figure 1). The sensors were placed according to the myoMotion protocol described in the manual. At the beginning of the measurement, each participant was checked, and the system calibrated according to the factory recommendations. The maximal sampling rate for a given sensor was 100 Hz per sensor for the whole 16-sensor set. We used system-build fusion algorithms and Kalman filtering (digital bandpass FIR filter). This approach allowed direct access to all unprocessed IMU sensor data for further computations.



Figure 1. The measurement set-up with the computer workstation and locations of the sensors on the worker's body.

The standardised machining tasks involved (Figure 2): picking up four pieces at a time (three pieces in one hand and one piece in the other) from a metal container, clearing metal chips from the clamping base, attaching the pieces to the clamping device, starting the deburring process, placing the pieces in the engraving machine, starting the marking (engraving) cycle, visual inspection of the correctness of the operations carried out and, finally, placing the pieces on the hanger. Handling and operating the pieces at the machine was done single-handedly; picking up and moving on to the subsequent process was done two-handedly.

The weight of the handled component was about 520 g before the operation and 380 g after the operation.

The standardised assembly tasks (assembling the spring-piston unit) involved the following (Figure 2): picking up the spring from the spring pack container (with left hand) and the piston from the piston box (right hand), placing the spring pack vertically in the centring sleeve, and the piston on the spring pack, visual inspection of the correctness of the operations carried out and, finally, moving the spring-piston unit towards the next assembly slot. The weights of the assembled components were from around 100 to 400 g.

The repetitive tasks of all the workers were monitored during a 30 min observation period by an experienced technician utilising the same procedure.



Figure 2. A sequence of production activities at the machining (above) and assembly workstation (below).
[Used with permission]

The production company employed ergonomic standards for studied workstations. Mainly, the working process is assessed at least every 3 years (“ergochecks”) according to the following physical criteria: (1) identification of high-risk factors using tailored risk assessment checklist (2) repetitive movements (ISO 11228-3 norm and the OCRA method in the risk assessment), (3) carrying, pushing and pulling objects (ISO 11228-1 and ISO 11228-2 norm), (4) lifting loads one-handed (EN 1005-2 norm) and two-handed (NIOSH norm). Besides, the company uses internal norms for all factory units. Mainly, they refer to load evaluation of hand, arm and fingers. What is more, all measurements mentioned above were established in relation to EN and ISO norms, including the characteristics of participants’ work, especially repetitive handling for high frequency (EN 1005-5 and ISO 11228-3), carrying, pushing and pulling objects and force limits (EN 1005-3 and ISO 11228-2 norms) lifting loads one-handed (EN

1005-2 norm ISO 11228-1). The references to ergonomics norms mentioned above were conducted throughout the measurement collection.

The data collected during the measurement were pre-processed by reviewing and discarding incorrectly recorded records (1 case). Each record was then verified against the workstation manual.

Data Processing

Workers' performance during professional activities (working operations) at the workstation was characterised comprehensively by different assessment levels and concerned, particularly, the measurement of mobility, (bio)energetics of movement, and inertial loads of involved body parts. Biomechanical and statistical calculations aimed to select the most relevant variables that are easy to interpret and could serve to clarify the research goals. All derived formulas conformed with classical mechanics and biomechanical standards on reporting human movement. Additionally, as mentioned above, the chosen variables correspond to general norms devoted to assessing risks for repetitive tasks, working postures, and force limits for machinery operations.

The production cycles of each employee were characterised by the number of cycles and the cycle time [in s]. The time at which the worker reached for the component was chosen as the beginning of the cycle.

The mobility of the employees for machining or assembly workstation employees were characterised separately by measuring angular displacements of the main body parts involved in the work, in particular: movement of the pelvis, lower back (loins), upper trunk (thorax), shoulder complex (links the upper arm to the axial skeleton at the thorax), upper arms, and arms connected by elbow joints. Following the International Society of Biomechanics' recommendations for the reporting of human joint motion (Bańkosz & Winiarski, 2020, 2021), the following angles (measured in degrees) were chosen for both sides and sampled every 0.01 per cent of cycle time (Figure 3), in particular:

- for the pelvis—pelvic tilt: forward (positive) or backward (negative) movement of the pelvis (with respect to the global coordinate system) in the sagittal plane; pelvic obliquity: upward (positive) or downward (negative) movement of the pelvis in the frontal plane; pelvic rotation: internal (positive) or external (negative) movement of the pelvis in the transversal plane
- for the lower trunk—lumbar flexion-extension: anterior (positive) or posterior (negative) movement of the loins in the sagittal plane; lumbar lateral flexion: movement of the loins to the left (upward) or right (downward) side in the frontal plane; lumbar internal-external rotation: internal (positive) or external (negative) movement of the loins in the transversal plane
- for the upper trunk: thoracic flexion-extension: anterior (positive) or posterior (negative) movement of the thorax in the sagittal plane; thoracic lateral flexion: movement of the thorax to the left or right side in the frontal plane; thoracic internal-external rotation: internal (positive) or external (negative) movement of the thorax relative to the global coordinate system in the transversal plane
- for the shoulders: left/right shoulder flexion-extension: anterior (positive or posterior (negative) movement of the humerus relative to the thorax in the sagittal plane; left/right

shoulder abduction-adduction: abduction (positive) or adduction (negative) of the humerus relative to the thorax in the frontal plane; left/right shoulder internal-external rotation: internal (positive) or external (negative) rotation of the humerus in the transversal plane

- for the elbows: left/right elbow flexion-extension: positive (flexion) or negative (hyperextension) movement of the forearm relative to the humerus along the transversal axis

The movement of hands with respect to forearms had to be excluded in the study due to the presence of protective gloves that would significantly interfere with the installation of the IMU sensor and could influence the production cycle. Similarly, the employees' standing posture determined that the analysis of the movement of the lower extremities has been omitted. The following parameters were chosen to characterise the mobility graphs: maximum value (Max), minimum value (Min), the median value of angular position (median) together with cycle variation characteristics—interquartile range (IQR, for skewed distributions) and coefficient of variation (CV = standard deviation/mean). Movements characterised by extremal (Min or Max) median angle values, asymmetry of movements (mainly excessive tilts from the neutral position or side differences) or extremally low or high movement variability characterised by the CV were considered as a potential risk symptom in work-related musculoskeletal disorders (WRMDs).



Figure 3. Angular values (temporal angular trajectories) characterising the movements of the tested joints.

The energetics of movements was characterised by the total mechanical energy (TME) expenditure and the average mechanical power (rate of change in TME). The total mechanical energy (TME) comprises of the instantaneous potential energy (PE) and instantaneous kinetic energy (KE) of the resultant centre of gravity (CoG) of the body, according to equation (Eq.1):

$$\begin{cases} PE(t) = M \cdot g \cdot h_{CoG}(t) \\ KE(t) = \frac{1}{2} \cdot M \cdot v_{CoG}^2(t) \end{cases}, \quad (\text{Eq. 1})$$

where M is the total body mass [in kg], $g = 9.81 \text{ [m}\cdot\text{s}^{-2}]$ is the gravitational constant, $h_{CoG}(t)$ is height of the CoG [in m], and v_{CoG} is resultant speed of CoG [in $\text{m}\cdot\text{s}^{-1}$]. The velocity of the CoG was computed by integrating the triaxial information from the accelerometers (Figure 4).

For the calculation of instantaneous PE, only an increase in the height of the CoG (CoG amplitude) was considered so that the minimum values of PE and KE were equal to 0. The TME was the sum of total PE and total KE over the whole measurement period considered. Finally, the energy values were normalised against time to compare the values to tabulated data and expressed per minute of work, forming the average mechanical power [in joules per minute of work].

Similarly, parameters like Min, Max, Median, IQR and CV were chosen to characterise the energetics of movements. Extremal (Min or Max), median values, or extremally low/high energy cost variability were considered a potential risk symptom of WRMDs.



Figure 4. Acceleration values (3D signals from triaxial accelerometers).

At the last stage of data processing, the variables characterising *inertial loads of the body parts* were determined. In the case of linear movements, inertial loads were defined as the product of mass and resultant linear acceleration and in angular movements as the product of moment of inertia and angular acceleration, according to Eq. 2.

$$\begin{cases} Load_{linear} = M \cdot |\vec{a}| \\ Load_{angular} = I \cdot |\vec{\epsilon}| \end{cases} \quad (\text{Eq. 2})$$

where M is body mass [in kg], I is moment of inertia [in $\text{kg}\cdot\text{m}^2$], $|\vec{a}|$ is the resultant linear acceleration [in $\text{m}\cdot\text{s}^{-2}$], and $|\vec{\epsilon}|$ is resultant angular acceleration [in $\text{rad}\cdot\text{s}^{-2}$].

For this purpose, an estimation of the mass and length of each body segment was performed for each individual (Figure 5), using inertial coefficients according to (de Leva, 1996). Ultimately, characteristics of body parts involved the relative mass ratio (total weight * mass ratio), the relative position of the centre of mass on the long axis (segment length * length ratio) and the principal radii of inertia coefficients (de Leva, 1996; Derrick et al., 2020). The triaxial accelerations of the IMU sensors placed on different parts of the body (blue squares in Figure 1) were determined (in particular on the pelvis, lower back (lumbar) spine, upper (thoracic) spine, left/right upper arm, left/right forearm) and measured in one-thousandths (milli) of the earth's acceleration (mG).

Finally, the parameters Min, Max, median, IQR and CV were chosen to characterise the inertial loads of main body parts involved in work. Extremal (Min or Max), median values or extremally low / high variability in the inertial loads were considered as a potential risk symptom in WRMDs.



Figure 5. The three degree and 16 body parts model for the determination of segment mass and length.

Statistical Calculations

Statistical calculations were performed using Statistica 13.1 (TIBCO Software Inc.). The normality of the distribution of continuous variables (for each extracted variable in each test group) was tested by the Shapiro-Wilk test. Nonnormal variables were reported as median and $\pm$ interquartile range ($\pm$ IQR). The IQR, also called the midspread, is a measure of statistical dispersion around the median, equal to the difference between upper and lower quartiles ($IQR = Q3 - Q1$). The Mann-Whitney U test was used to assess the differences between machining (MWE) and assembly (AWE) workstation employees (with the $\alpha = 0.05$ level of significance) based on the normality test results. MWE and AWE workstations appear similar in terms of standing posture and work characteristics (common is the job rotation) but may significantly differ in activity, workload or energy cost. The statistical power was sufficient to detect the described differences. Especially for the extracted data, the partial η^2 effect size was found to be between 0.68 and 0.88. In addition to the median value, the Min, Max, and CV were averaged for all employees and devices. The descriptive analysis included repeatability analysis employing the Coefficient of Variation (CV). The following interpretation for the movement variability based on the CV was adopted: $CV < 50\%$ was considered as low variability/diversity (and high repeatability); $50\% < CV < 100\%$ as moderate variability; $CV > 100\%$ as high variability (and low repeatability).

RESULTS

Production Cycles

Descriptive analysis of production cycles, including the number of cycles and cycle time duration [in s] for both the machining workstation employees (MWE) and assembly workstation employees (AWE), is provided in Table 1.

Table 1. Descriptive Analysis of Production Cycles Characterised by the Median Value (Med) and Interquartile Range ($\pm$ IQR), Min, Max, and Coefficient of Variation (CV) for Both Machining and Assembly Workstation Employees (MWE and AWE).

Variable	Machining workstation employees				Assembly workstation employees			
	Med $\pm$ IQR	Min	Max	CV (%)	Med $\pm$ IQR	Min	Max	CV (%)
Number of cycles [l]	5.8 $\pm$ 2.3*	2	17	43.1*	18.1 $\pm$ 5.2	15	38	33.3
Cycle time [s]	201.2 $\pm$ 96.6*	28.4	375.2	53.0*	12.7 $\pm$ 4.4	8.1	30.4	34.7

Note. * denotes changes statistically significant at $\alpha < 0.05$

The work of those in the MWE group was characterised by a smaller number of production cycles (from 2–17; 5.8 on average) but a longer time of cycles (201.2 s). Those in the AWE group had more cycles (from 15–38; 18.1 on average), but it was compensated for by a shorter cycle time (12.7 s). The work on assembly positions was significantly more repetitive (less variable).

Mobility

Descriptive analysis of mobility characterising angular displacements of the main body parts involved in the work, for both the MWE and the AWE is presented in Table 2.

Table 2. Descriptive Analysis of Mobility. Joint Angles [in degrees] for the Movement of Different Body Parts Characterised by the Median Value (Med) and Interquartile Range ($\pm$ IQR), Min, Max and Coefficient of Variation (CV) for Both Machining and Assembly Workstation Employees (MWE and AWE).

Body parts	Angle [deg]	Machining workstation employees				Assembly workstation employees			
		Med $\pm$ IQR	Min	Max	CV (%)	Med $\pm$ IQR	Min	Max	CV (%)
Pelvis	Pelvic tilt	1.9 $\pm$ 2.8	-8.0*	24.9*	211.5	0.1 $\pm$ 2.9	-5.7	10.3	6.7
	Pelvic obliquity	-0.8 $\pm$ 2.0	-13.6*	13.7*	30.5	-0.7 $\pm$ 3.1	-6.9	6.5	264.0
	Pelvic rotation	-0.1 $\pm$ 1.2	-21.1*	21.2*	250.3	0.0 $\pm$ 3.0	-12.8	12.8	990.8
Loins	Lumbar flex-ext	5.7 $\pm$ 6.1	-4.6*	29.3*	59.9	5.5 $\pm$ 2.5	1.0	11.6	53.2
	Lumbar lateral flex	0.2 $\pm$ 3.8	-10.6	12.2*	163.7	1.2 $\pm$ 2.2	-3.1	6.2	58.2
	Lumbar rotation	1.4 $\pm$ 5.5	13.7	17.2*	82.9	1.7 $\pm$ 2.4	-4.1	6.7	37.4
Thorax	Thoracic flex-ext	1.3 $\pm$ 3.1	-12.2	13.2*	67.4	1.3 $\pm$ 2.6	-5.0	6.1	22.5
	Thoracic lateral flex	0.0 $\pm$ 3.9	-11.3	13.7*	230.3	-0.7 $\pm$ 2.1	-5.7	3.6	21.7
	Thoracic rotation	2.9 $\pm$ 6.7	-16.7	20.3*	97.7	-1.6 $\pm$ 3.3	-8.6	5.7	17.8
Shoulder	LT Shoulder flexion	16.4 $\pm$ 18.8	-20.3	71.5*	133.6	12.1 $\pm$ 16.4	-10.8	55.4	169.5
	RT Shoulder flexion	23.5 $\pm$ 19.4	-13.3*	77.0	90.8	18.3 $\pm$ 13.2	-9.4	63.3	48.2
	LT Shoulder abduction	8.4 $\pm$ 12.3	-30.3*	58.6	198.8	12.1 $\pm$ 11.5	-7.1	44.9	124.1
	RT shoulder abduction	6.5 $\pm$ 7.6	-45.4*	66.1*	163.9	12.3 $\pm$ 12.4	-11.1	47.9	502.5
	LT shoulder rotation	-43.9 $\pm$ 16.3	-95.4*	3.2*	70.3	-39.1 $\pm$ 12.3	-68.3	-8.7	34.4
	RT shoulder rotation	-50.8 $\pm$ 16.5	-102.3*	0.2	36.1	-38.4 $\pm$ 15.1	-70.8	-0.9	53.0
Elbow	LT Elbow flexion	32.3 $\pm$ 16.4	-14.2*	92.2	96.9	57.3 $\pm$ 19.1	5.9	87.6	53.0
	RT Elbow flexion	33.1 $\pm$ 15.5	-14.9*	94.0	83.0	51.5 $\pm$ 18.8	1.2	86.5	47.1

Note. * denotes changes statistically significant at $\alpha < 0.05$

Movement of the pelvis, assessed in three movement planes, was characterised for both the MWE and AWE groups by a relatively symmetrical pattern (median angle values close to neutral position or Min/Max values evenly distributed), except pelvic tilt for the MWE, which was significantly tilted to the front by 1.9 deg. Movement of the pelvis for MWE was characterised by a statistically significant higher range (Max–Min) than for the AWE group. Variation in those movements was from low (for the fore-aft tilt of AWE and left-right obliquity of MWE) to high (pelvic tilt and rotation of MWE and pelvic obliquity of AWE) and even very high (for pelvic internal-external rotation of AWE).

The movement of the lower trunk (loins) was somewhat asymmetrical for both the MWE and AWE groups. On average, the loins were forwardly flexed (anteriorly tilted) by around 5.5 deg. from their neutral position (both groups). Besides, the range of these asymmetrical movements differentiated the two groups. The range of all movements for the MWE group was

significantly higher than for the AWE group. The variability in these movements was relatively moderate except for side flexion (obliquity) for the MWE group, which was high.

A similar pattern was observed for the movements of the upper trunk (thorax). Movements, especially rotational, were asymmetrical. On average, the thorax was internally rotated by 2.9 deg. for MWE and externally rotated by 1.6 deg. for AWE. Similarly, the range of thorax movements was higher for the MWE than for the AWE group. There was moderate variability and repeatability of thoracic movements. Similarly, the thoracic lateral flexion for the MWE group was the most variable (and the least repetitive).

Movements of arms in the shoulder joint were assessed independently for the left and right sides in three planes of motion. The median angle values were far from the neutral (zero) values, which suggests they were persistently used throughout the whole working process. The median shoulder flexion value for the MWE group was higher than for the AWE group, both for the right and left sides, but the differences are insignificant mainly because of the high variation in these movements. What could also be seen is that the AWE group's upper arm was abducted more than that of the MWE group for both sides. Both groups had their shoulders externally rotated (more than 38 deg. for MWE and more than 44 deg. for AWE on both sides). Again, the range of movements was significantly higher for the MWE group with variation from moderate to very high, especially for the shoulder abduction angle.

The elbow joint was at 30 deg. of flexion for the MWE and 55 deg. of flexion for the AWE group throughout the whole observation period, ranging from 90 deg. for the AWE to 105 deg. for the MWE group. The differences were statistically significant. The repeatability of these movements was moderate—higher for the AWE than for the MWE group.

Energetics of Movements

The energetics of movements was characterised by the total mechanical energy (sum of instantaneous kinetic and potential energy) and the average mechanical power (rate of change in TME). The results of the calculations are presented in Table 3.

Table 3. Descriptive Analysis Of The Energetics Of Movements. Instantaneous Mechanical Energy And Total Mechanical Work During the 30 min Observation [in kJ] Characterised by the Median Value (Med) and Interquartile Range ($\pm$ IQR), Min, Max and Coefficient of Variation (CV) for both Machining and Assembly Workstation Employees (MWE and AWE).

Variable	Machining workstation employees			Assembly workstation employees		
	Med $\pm$IQR	Max	CV (%)	Med $\pm$IQR	Max	CV (%)
<i>Instant. Potential Energy [J]</i>	786.7* $\pm$ 13.8	801.8*	15.0	613.6 $\pm$ 12.7	618.6	12.4
<i>Instant. Kinetic Energy [J]</i>	0.1 $\pm$ 0.3	12.2*	266.3	0.1 $\pm$ 0.2	2.5	152.9
<i>Total Mechanical Energy [kJ]</i>	141.62 $\pm$ 19.40	345.95*	87.9	110.42 $\pm$ 18.10	211.31*	78.8
<i>Average Power [J/min]</i>	5634.3 $\pm$ 557.8	6807.2	189.6	4394.1 $\pm$ 19	5676.5	94.8

Note. * denotes changes statistically significant at $\alpha < 0.05$

The instantaneous potential energy (PE) depended on an individual's mass and body height and was normalised to body length. Due to a larger amplitude of the CoG, the PE was also larger for MWE group by 170 J on average. The minimal value of the instantaneous PE and KE was equal to 0 and was omitted from the table. The KE was dependent on the speed of the CoG but had a low contribution to the total energy (compared to PE)—maximally only 12.2 J (for MWE) or 2.5 J (for AWE). There were almost no differences between the groups, which is why the total energy expenditure (during the 30 min of work) was 141.6 kJ (for MWE) and 110.4 kJ (for AWE) or 5634.3 J/min (for MWE) and 4394.1 J/min (for AWE) on average. The highest values of the average power (P) reached 6807.2 (for MWE) or 5676.5 (for AWE) and were statistically significant. The variance of the results was low (for the values of PE) and rather high or very high for the values of KE, TME, and P.

Inertial Loads of Body Parts

Descriptive analysis of mobility characterising inertial loads of different body parts involved in the work for both the MWE and AWE is presented in Table 4.

Table 4. Descriptive Analysis of the Inertial Loads of Main Body Parts Involved in Work Characterised by the Median Value (Med) and Interquartile Range ($\pm$ IQR), Min, Max and Coefficient of Variation (CV) for Both Machining and Assembly Workstation Employees (MWE and AWE).

<i>Variable</i>	Machining workstation employees			Assembly workstation employees		
	Med $\pm$IQR	Max	CV (%)	Med $\pm$IQR	Max	CV (%)
<i>Pelvis load [N]</i>	14.7 $\pm$ 13.3	79.0	92.8	10.2 $\pm$ 7.3	75.1	72.9
<i>Loins load [N]</i>	15.1 $\pm$ 10.3	69.3	83.9	11.0 $\pm$ 7.6	66.3	71.0
<i>Thorax load [N]</i>	15.7 $\pm$ 9.0	73.2	78.7	11.4 $\pm$ 7.7	69.2	69.3
<i>LT Upper arm load [N]</i>	29.8 $\pm$ 21.2	181.6*	91.9	27.2 $\pm$ 19.7	135.8	86.1
<i>RT Upper arm load [N]</i>	34.5 $\pm$ 14.9	173.0*	75.2	33.7 $\pm$ 21.5	151.7	79.4
<i>LT Forearm load [N]</i>	39.5 $\pm$ 16.7	193.3*	85.7	37.5 $\pm$ 23.7	161.3	82.6
<i>RT Forearm load [N]</i>	40.7 $\pm$ 28.3	284.6*	95.5	38.5 $\pm$ 32.5	263.0	83.2

Note. * denotes changes statistically significant at $\alpha < 0.05$

All inertial load values for each segment of the MWE group tended to be higher than for the AWE group, but the differences were statistically insignificant due to the high deviation in the results. The inertial load was based on the resultant acceleration of each segment. That is why the minimal value (0) was omitted from the table. The lowest values of inertial load were noticed for the lower body parts, owing to small acceleration. Although the mass of these segments is relatively high, the overall load is relatively low. The highest median values of inertial loads (40 N) were noticed for the MWE group's forearm movement (right side). However, some workers achieved values of up to 285 N due to high acceleration and deceleration periods in forearm movement. The variance of the results was moderate, ranging from 71% to 95%

DISCUSSION

According to the United States Bone and Joint Initiative (USBJI), the US national action network of the Global Alliance for Musculoskeletal Health, adults in the workplace reported nearly 364 million lost workdays due to different musculoskeletal conditions—more than any other chronic health condition (Lezin & Watkins-Castillo, 2018). Repetitive motions, such as twisting, pushing, lifting, pulling, prolonged sitting or standing, unhealthy posture, and vibrations, can cause or aggravate musculoskeletal disorders (Antwi-Afari et al., 2017; Lezin & Watkins-Castillo, 2018). Several ergonomic risk assessment methods have been developed to improve the prevention, diagnosis, or treatment of musculoskeletal conditions and identify risk factors to make measurable improvements in the work environment. Among these methods, observational methods based on objective measurement in the work environment are among many ergonomic assessment tools to evaluate ergonomic risk factors that have gained high recognition (Antwi-Afari et al., 2017; Nunes, 2009). Motion capture is a powerful tool used in many applications for human motion capture, ranging from the entertainment industry to medicine and sports.

The motion capture system in our study assessed the mobility of different movements and the energy cost and loads of different body parts at assembly or machining workstations. Briefly, the most startling findings were as follows: the asymmetrical and countermovement positioning of the pelvis with respect to the loins and whole trunk for AWE induces twists and stresses that could produce lumbar intradiscal pressure; the median angle values of the pelvis were far from neutral (zero) values, which suggests they are persistently used throughout the whole working process; the movements of the upper limbs and trunk were characterised on average by noticeably low angular velocities; the change in kinetic energy was relatively small; and the highest values of accelerations were registered with a strong predominance of right upper-limb movements. The accelerations of the pelvis, loins, and thorax were relatively small. The highest range of movement for the pelvis was noted for pelvic rotation (31 deg.). Pelvic movements were relatively symmetrical (~0 deg. with small intersubject deviation from the median). The highest range for the loins (lower trunk) was spotted for the flexion-extension movement in the sagittal plane (18 deg.) and lateral flexion in the frontal plane (19 deg.) with an asymmetrical pattern (median position around 2–5 with moderate intersubject deviation). The thorax (upper trunk) was used in all planes: in the sagittal plane with a range of 16 deg., in frontal with a range of 15 deg., and mainly in the transversal with a range of 22 deg., on average. The movements were reasonably symmetrical with moderate (for the thorax flexion-extension and lateral flexion) or high (for the rotation) variability. These findings imply a high risk of work-related problems in the pelvis and lower trunk due to asymmetrical positions and excessive rotation. However, the findings revealed relatively no risks for the thorax.

The typical, normative pelvis, loins, and thorax values are hardly used in the ergonomic assessment. The motion capture method gives a broader perspective on human performance analysis, work-related musculoskeletal disorders, and injuries assessment. Our study noted the highest dynamic range of movement in the shoulder and elbow joints (Table 2). The range for shoulder flexion-extension was around 75 deg., around 65 deg. for abduction-adduction, and from 75 to 82 deg. for rotation with a high predominance of right upper-limb movements. These ranges correspond to 36% (for shoulder abduction-adduction) or 55% (for shoulder rotation) of the normative range of movement (50 percentile) when compared to normative joint

movement ranges for males and females aged 20–44 (Soucie et al., 2011; Stubbs et al., 1993). Also, the elbow flexion-extension was of the order of 90–95 deg., with a high predominance of the right. To be noted is the asymmetrical positioning of the pelvis with respect to loins for the AWE group. Pelvis and loins were rotated internally (with median position 1.7 ± 2.4 with min -4.1 to max 6.7 deg.) and thorax rotated externally (median -1.6 ± 3.3 , min -8.6 to max 5.7 deg.). The difference was around 3.5–10.0 deg., on average. This compensation mechanism for prolonged asymmetric conditions could lead to low back pain. Furthermore, the median angle values were far from neutral (zero) values, which suggests they are persistently used throughout the whole working process. Both groups had their shoulders externally rotated (more than 38 deg. for MWE and more than 44 deg. for AWE on both sides) which is common in manipulative hand movements and power grasping tasks (Jafari et al., 2018). The variation in these movements, especially during flexion-extension and abduction-adduction on the left side, was high or very high, suggesting high upper-limb involvement. Additionally, the symmetry between sides often exceeded the assumed 10% level, which further indicates a possible risk of musculoskeletal overload.

Findings from this in-depth analysis suggest the need for a redesign of the workstation and production system. Regarding norms for manual handling tasks (Ciriello & Snook, 1999; SHOAF et al., 1997; Snook & Ciriello, 1991), both AWE and MWE hold an upper limb too long in an extended position, especially for shoulders and elbows. Most of the registered deviations from neutral (standing) position for the trunk fell into either Green or Yellow preferred Zones for angular measurements of range of motion (ROM) as defined by Chaffin et al., 2006 and Woodson et al., 1992 (adopted by Openshaw & Taylor, 2006). According to the trunk ROM limits upper bands for the second, Yellow Zone should not exceed 25 deg for back flexion, 10 deg for back extension, 10 deg for lateral bend or 25 deg for back rotation, which corresponds to the lumbar flexion-extension, lumbar lateral flexion or lumbar rotation in our study. Some of the MWE workers (with extremal ROM values of around 29 deg of lumbar flexion or 12 deg of lumbar lateral flexion) fell into the third, Red Zone posing a potential WRMSD risk factor. Findings from the motion capture system may be used both as a replacement and complement to standardised ergonomic assessment tool as RULA (Rapid Upper Limb Assessment).

Maintaining proper body posture and movement during work is essential! The human pelvis supports the abdomen's contents while also transferring weight from the spine to the lower limbs. The lower and upper joints work together to decrease the force transferred from the ground to the spine and upper extremities during movement. During working manoeuvres, the shoulder girdle structures are designed primarily for mobility, allowing both to move and position the upper limbs through a wide range of space and the greatest range of motion for any joint. In a systematic review by Swain et al. (2020), a consensus was established for the absence of an association between exposure to prolonged or occupational standing, sitting, bending, and twisting, awkward postures, and low back pain (LBP). The evidence was conflicting for the other physical exposures examined, including sagittal spine curvatures, prolonged or occupational standing, awkward postures, bending and twisting movements of the spine, components of heavy physical work, and whole-body vibration (Swain et al., 2020). When considering meta-analyses alone, consistent, significant, and positive associations were demonstrated between maintaining flexed and awkward postures and LBP (Griffith et al., 2012). Acute, nonspecific LBP, which is not attributable to a recognisable or known specific

pathology, can lead to subacute or even chronic low back pain (Burton et al., 1995). The strategy for finding a cause of the nonspecific low back pain is problematic; it is crucial to understand the functional lumbar spinal unit. Several methods have been developed to diagnose WRMSDs. Most of them are based on job surveys and surveillance techniques (Kroemer et al., 2018; Marras & Karwowski, 2006). As suggested in the literature (Garg & Kapellusch, 2009), this method might assess and predict WRMSDs risks better than questionnaire-based methods (Buckle & Jason Devereux, 2002; Garg & Kapellusch, 2009).

The information on energy transfer (Table 3) during operation is also invaluable. A person at rest has a constant energy consumption—a basal metabolic rate (BMR) expended in a neutral environment. An adult man requires, on average, about 1700 kcal (7000 kJ) and a woman about 1400 kcal (5900 kJ) per day (Hills et al., 2014). With work, depending on its intensity, the energy requirements of the body increase. The net energy cost in our experiment was related to the component lifting (and the change in potential energy, PE) and the development of angular velocities at the joints (kinetic energy, KE). The KE was dependant on the speed and had a low contribution to the total energy (compared to PE). In summary, the total energy expenditure (during the 30-min observation) was 5634.3 J/min (for MWE) or 4394.1 J/min (for AWE) on average, with the highest values for the average power reaching 6807.2 J/min (for MWE) or 5676.5 (for AWE). According to Lehmann's chronometric-tabular method, values in the range 3350–6280 kJ per shift for men and 2930–4187 per shift for women correspond to a moderate degree of work severity (Haggarty et al., 1997; Hills et al., 2014; Pałęga, 2019). The mean values in our measurement corresponded to the moderate level of work, but some of the workers (with Average Power of around 6800 J/min) fell into the severe work category posing a potential WRMSD risk factor.

This paper also presents a conceptual model of the interaction between the body parts and external factors influencing the musculoskeletal system (biomechanical load) during operations (Table 4). The main body parts' load was related to the moment of inertia and speed rate measured by the accelerometers. The extremal values of inertial loads were registered for the forearms (around 280 N) and the upper arms (~180 N), with a strong predominance of right upper-limb movements. The pelvis, loins, and thorax accelerations were relatively small, and did not influence the outcome loads. Regrettably, there are no corresponding EN or ISO norms concerning inertial loads. EN 1005-3 involves isometric forces (static loads), which could serve as a baseline for our measurements. E.g., it refers to forces of arms and forearms with values between 50-75 N, or the isometric force capacity limits (for actions for professional use) of 225-275 N during pushing and pulling with trunk support (EN 1005-3, 2002). By using the proposed biomechanical model, following quantitative verification, the relevance of this information to industry consists of providing safety levels that can result in improved work and protection for workers against WRMSDs. Intense physical workload, such as pushing, pulling, lifting, carrying, or manipulating a heavy load, is a common task leading to the development of WRMSDs (Limong & Widajati, 2021; Pistolesi & Lazzerini, 2020; Roman-Liu, 2013). Particular tasks, like lifting and handling patients, especially with physical effort (Doda et al., 2020), also posed risks for the low back. However, even light manual work at an assembly line, such as packing small objects, etc., which mostly involves using upper limbs for repetitive tasks with a static load on the back, also causes musculoskeletal disorders (Bosch et al., 2007; Fu et al., 2019). Many systematic reviews have confirmed that repetitive and forceful upper-

limb movements are risk factors for developing WRMSDs (Hanvold et al., 2019; Hulshof et al., 2021; van der Windt, 2000).

Based on the data analysis, it can be concluded that human movement analysis makes it possible to determine the level of somatic (physical and physiological) well-being. It accurately determines the level of load on the joints during the performance of activities at the workplace—its objective—and allows for the study of many variables. However, it is difficult to determine on the basis of this methodology whether we are dealing with overload in relation to the daily functioning of a person. The questionnaire method, which is the subjective opinion of the person being examined, complements a biomechanical examination. Undoubtedly, the use of both methods is most desirable and would allow for a comprehensive study of the level of well-being within the organisational environment. To a greater extent, these methods make it possible to create a forecast of the future state and recommendations for work ergonomics and work environments. Activities of this type also illustrate the need for interdisciplinarity in conducting scientific research.

Finally, it is worth noting that the various ergonomic workstation research tools, injury risk, or WRMSD, do not examine human movements comprehensively – in terms of all possible body parts or movements. For example, ranges of arm movements are carefully examined (RULA - Rapid Upper Limb Assessment), or the main parts and movements of the entire body (REBA - Rapid Entire Body Assessment) in terms of the selected neck, trunk, arms, legs and wrists positions or adjustments. Whereas the motion capture system objectively monitors all movements in terms of their amplitude, variability, symmetry and frequency, estimates segmental loads and energy cost, which is undoubtedly an added value of the motion capture technology for occupational health and safety innovations.

Limitations of the Study

The investigators took exceptional care to avoid sources of bias and confounding in their studies by eliminating movements unrelated to the studied work tasks. Still, a few movement artefacts may have remained when analysing long stretches of work associated with unpredictable interruptions or incidents during production and the work process.

Although characterised as having three degrees of freedom, the trunk's movements are quite constrained at a single vertebral level. The lumbar and thoracic areas of the vertebrae allow the trunk to flex and extend, but this plane of movement is limited in the middle thoracic portion of the vertebrae. Similarly, the rotation of the trunk occurs primarily in the thoracic regions because the lumbar region has limited movement potential in the horizontal plane. It is only the combination of all vertebral segments that allow the 3D movement produced by the spine. Moreover, the concept of total mechanical work based on the movement of the CoG does not characterise the work of different body parts.

The inertial load was calculated based on the central moment of inertia of a body part (along the central rotational axis) and involved only the body part without considering the weight of the handled component, which varied during the machining/assembly process. In this simplification, the mass of a component was negligibly small compared to the mass of a body segment. Studies investigating risk factors for the development of WMSD should report in detail the exposure levels. Individual risk factors associated with WMSD should be considered.

CONCLUSIONS

The analysis of ergonomics of human motion at work helps in improving workstations' ergonomics, increases workers' and organisational productivity, and may enrich H&S procedures. Human movement analysis makes it possible to determine the level of somatic (physical and physiological) well-being. The most valuable findings of the study, associated with risk symptoms in work-related musculoskeletal disorders, were the following:

- countermovement positioning of the pelvis with respect to loins for a prolonged duration, which could lead to back pain
- combination of median angle values and excessive body part load suggest overuse of joints throughout the whole working process
- the variation in movements, especially during flexion-extension and abduction-adduction on the left side, was high or very high, suggesting high upper-limb involvement
- low variation in movements of the pelvis, loins, and thorax suggests static posture during operations
- a strong predominance of right upper-limb movements

IMPLICATIONS FOR RESEARCH

As shown, the IMAS gives a wide variety of variables that could be measured and investigated in a workstation during everyday tasks. It allows H&S specialists and ergonomists to plan and organise work in accordance with healthy workplace standards. In terms of health and safety risk factors, the IMAS also enables in-depth analyses to reduce or even eliminate them. The results allowed us to generate recommendations for HR, H&S, and ergonomics procedures. Firstly, the method and findings might help improve workstation ergonomics, increase workers' and organisational productivity, enrich H&S procedures, and improve automation on production lines. Firstly, job rotation and methods-time measurement (MTM) might be improved. Secondly, health interventions, including physiotherapeutic exercises to prevent asymmetry and spine-related diseases, should be implemented. Finally, a company received detailed instructions on how to improve workstation ergonomics, including an in-depth analysis of workers' movements during manual handling, which can be used to complement the standard ergonomic procedures to avoid or reduce forceful exertion, awkward postures, and repetitive motion.

ENDNOTES

1. European Survey of Enterprises on New and Emerging Risks (ESENER), 2019, 45,420 establishments, EU 28 countries+ Iceland, North Macedonia, Norway, Serbia and Switzerland
2. Eurostat, Labour Force Survey ad hoc module 'Accidents at work and other work-related health problems' (2013).

REFERENCES

- Antwi-Afari, M. F., Li, H., Edwards, D. J., Pärn, E. A., Seo, J., & Wong, A. Y. L. (2017). Biomechanical analysis of risk factors for work-related musculoskeletal disorders during repetitive lifting task in construction workers. *Automation in Construction*, 83, 41–47. <https://doi.org/10.1016/j.autcon.2017.07.007>
- Bańkosz, Z., & Winiarski, S. (2020). Statistical Parametric Mapping Reveals Subtle Gender Differences in Angular Movements in Table Tennis Topspin Backhand. *International Journal of Environmental Research and Public Health*, 17(19), 6996. <https://doi.org/10.3390/ijerph17196996>
- Bańkosz, Z., & Winiarski, S. (2021). The Application of Statistical Parametric Mapping to Evaluate Differences in Topspin Backhand between Chinese and Polish Female Table Tennis Players. *Applied Bionics and Biomechanics*, 2021, 1–11. <https://doi.org/10.1155/2021/5555874>
- Barim, M. S., Sesek, R. F., Capanoglu, M. F., Drinkaus, P., Schall, M. C., Gallagher, S., & Davis, G. A. (2019). Improving the risk assessment capability of the revised NIOSH lifting equation by incorporating personal characteristics. *Applied Ergonomics*, 74, 67–73. <https://doi.org/10.1016/j.apergo.2018.08.007>
- Beaucage-Gauvreau, E., Robertson, W. S. P., Brandon, S. C. E., Fraser, R., Freeman, B. J. C., Graham, R. B., Thewlis, D., & Jones, C. F. (2019). Validation of an OpenSim full-body model with detailed lumbar spine for estimating lower lumbar spine loads during symmetric and asymmetric lifting tasks. *Computer Methods in Biomechanics and Biomedical Engineering*, 22(5), 451–464. <https://doi.org/10.1080/10255842.2018.1564819>
- Bernard, B. (Ed.). (1997). *Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity and low back*. NIOSH report No. 97–141 <https://certisafety.com/pdf/mdwf97-141.pdf>.
- Bhattacharya, A., & McGlothlin, J. D. (Eds.). (2011). *Occupational Ergonomics - Theory and Applications* (Second Edi). CRC Press Taylor & Francis Group. <https://doi.org/10.1201/B11717/OCCUPATIONAL-ERGONOMICS-AMIT-BHATTACHARYA-JAMES-MCGLOTHLIN>
- Bosch, T., de Looze, M. P., & van Dieën, J. H. (2007). Development of fatigue and discomfort in the upper trapezius muscle during light manual work. *Ergonomics*, 50(2), 161–177. <https://doi.org/10.1080/00140130600900282>
- Buckle, P. W., & Jason Devereux, J. (2002). The nature of work-related neck and upper limb musculoskeletal disorders. *Applied Ergonomics*, 33(3), 207–217. [https://doi.org/10.1016/S0003-6870\(02\)00014-5](https://doi.org/10.1016/S0003-6870(02)00014-5)
- Burton, A. K., Tillotson, K. M., Main, C. J., & Hollis, S. (1995). Psychosocial predictors of outcome in acute and subchronic low back trouble. *Spine*, 20(6), 722–728. <https://doi.org/10.1097/00007632-199503150-00014>
- Chaffin, D. B., Andersson, G., & Martin, B. J. (2006). *Occupational biomechanics* (4th editio). Wiley-Interscience.
- Ciriello, V. M., & Snook, S. H. (1999). Survey of manual handling tasks. *International Journal of Industrial Ergonomics*, 23(3), 149–156. [https://doi.org/10.1016/S0169-8141\(97\)00032-2](https://doi.org/10.1016/S0169-8141(97)00032-2)
- Côté, J. N. (2012). A critical review on physical factors and functional characteristics that may explain a sex/gender difference in work-related neck/shoulder disorders. *Ergonomics*, 55(2), 173–182. <https://doi.org/10.1080/00140139.2011.586061>
- Dalgren, A. S., & Gard, G. E. (2013). Soft values with hard impact – a review of stress reducing interventions on group and organisational level. <http://Dx.Doi.Org/10.1179/108331909X12540993897810>, 14(6), 369–381. <https://doi.org/10.1179/108331909X12540993897810>

- De Angelis, M., Giusino, D., Nielsen, K., Aboagye, E., Christensen, M., Innstrand, S. T., Mazzetti, G., van den Heuvel, M., Sijbom, R. B. L., Pelzer, V., Chiesa, R., & Pietrantonio, L. (2020). H-work project: Multilevel interventions to promote mental health in smes and public workplaces. *International Journal of Environmental Research and Public Health*, 17(21), 1–23. <https://doi.org/10.3390/IJERPH17218035>
- de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics*, 29(9), 1223–1230.
- Derrick, T. R., van den Bogert, A. J., Cereatti, A., Dumas, R., Fantozzi, S., & Leardini, A. (2020). ISB recommendations on the reporting of intersegmental forces and moments during human motion analysis. *Journal of Biomechanics*, 99, 109533. <https://doi.org/10.1016/j.jbiomech.2019.109533>
- Doda, D. V., Wariki, W. M. V., Wungouw, H. I. S., Engka, J. N. A., Pangemanan, D. H. C., Kawatu, P. A. T., Marunduh, S., Polii, H., Sapulete, I. M., & Kaseke, M. M. (2020). Work related low back pain, psychosocial, physical and individual risk factors among nurses in emergency care unit. *Enfermería Clínica*, 30, 31–35. <https://doi.org/10.1016/j.enfcli.2020.06.009>
- Fox, R. R., Lu, M.-L., Occhipinti, E., & Jaeger, M. (2019). Understanding outcome metrics of the revised NIOSH lifting equation. *Applied Ergonomics*, 81, 102897. <https://doi.org/10.1016/j.apergo.2019.102897>
- Fu, J., Ma, L., Tsao, L., & Zhang, Z. (2019). Continuous Measurement of Muscle Fatigue Using Wearable Sensors During Light Manual Operations. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Vol. 11581 LNCS* (pp. 266–277). Springer Verlag. https://doi.org/10.1007/978-3-030-22216-1_20
- Gallagher, K. M., & Callaghan, J. P. (2015). Early static standing is associated with prolonged standing induced low back pain. *Human Movement Science*, 44, 111–121. <https://doi.org/10.1016/J.HUMOV.2015.08.019>
- Garg, A., & Kapellusch, J. M. (2009). Applications of biomechanics for prevention of work-related musculoskeletal disorders. *Ergonomics*, 52(1), 36–59. <https://doi.org/10.1080/00140130802480794>
- Griffith, L. E., Shannon, H. S., Wells, R. P., Walter, S. D., Cole, D. C., Côté, P., Frank, J., Hogg-Johnson, S., & Langlois, L. E. (2012). Individual participant data meta-analysis of mechanical workplace risk factors and low back pain. *American Journal of Public Health*, 102(2), 309–318. <https://doi.org/10.2105/AJPH.2011.300343>
- Haggarty, P., Valencia, M. E., McNeill, G., Gonzales, N. L., Moya, S. Y., Pinelli, A., Quihui, L., Saucedo, M. S., Esparza, J., Ashton, J., Milne, E., & James, W. P. T. (1997). Energy expenditure during heavy work and its interaction with body weight. *British Journal of Nutrition*, 77(3), 359–373. <https://doi.org/10.1079/BJN19970038>
- Hanvold, T. N., Kines, P., Nykänen, M., Thomée, S., Holte, K. A., Vuori, J., Wærsted, M., & Veiersted, K. B. (2019). Occupational Safety and Health Among Young Workers in the Nordic Countries: A Systematic Literature Review. *Safety and Health at Work*, 10(1), 3–20. <https://doi.org/10.1016/j.shaw.2018.12.003>
- Hills, A. P., Mokhtar, N., & Byrne, N. M. (2014). Assessment of Physical Activity and Energy Expenditure: An Overview of Objective Measures. *Frontiers in Nutrition*, 1. <https://doi.org/10.3389/fnut.2014.00005>
- Hulshof, C. T. J., Pega, F., Neupane, S., van der Molen, H. F., Colosio, C., Daams, J. G., Descatha, A., Kc, P., Kuijter, P. P. F. M., Mandic-Rajcevic, S., Masci, F., Morgan, R. L., Nygård, C.-H., Oakman, J., Proper, K. I., Solovieva, S., & Frings-Dresen, M. H. W. (2021). The prevalence of occupational exposure to ergonomic risk factors: A systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. *Environment International*, 146, 106157. <https://doi.org/10.1016/j.envint.2020.106157>
- Jafari, N., Adams, K., Tavakoli, M., Wiebe, S., & Janz, H. (2018). Usability testing of a developed assistive

- robotic system with virtual assistance for individuals with cerebral palsy: a case study. *Disability and Rehabilitation: Assistive Technology*, 13(6), 517–522. <https://doi.org/10.1080/17483107.2017.1344884>
- Karatsidis, A., Bellusci, G., Schepers, H., de Zee, M., Andersen, M., & Veltink, P. (2016). Estimation of Ground Reaction Forces and Moments During Gait Using Only Inertial Motion Capture. *Sensors*, 17(12), 75. <https://doi.org/10.3390/s17010075>
- Karimi, A., Dianat, I., Barkhordari, A., Yusefzade, I., & Rohani-Rasaf, M. (2020). A multicomponent ergonomic intervention involving individual and organisational changes for improving musculoskeletal outcomes and exposure risks among dairy workers. *Applied Ergonomics*, 88, 103159. <https://doi.org/10.1016/J.APERGO.2020.103159>
- Karwowski, W., & Marras, W. S. (2003). *Occupational Ergonomics - Principles of Work Design*. CRC Press. <https://doi.org/10.1201/9780203507926/OCCUPATIONAL-ERGONOMICS-WALDEMAR-KARWOWSKI-WILLIAM-MARRAS>
- Kim, H.-K., & Zhang, Y. (2017). Estimation of lumbar spinal loading and trunk muscle forces during asymmetric lifting tasks: application of whole-body musculoskeletal modelling in OpenSim. *Ergonomics*, 60(4), 563–576. <https://doi.org/10.1080/00140139.2016.1191679>
- Kroemer, K. H. E. ., Kroemer, H. B. ., & Kroemer-Elbert, K. E. (2018). *Ergonomics: how to design for ease and efficiency* (Third Edit). CRC Press.
- Laird, R. A., Gilbert, J., Kent, P., & Keating, J. L. (2014). Comparing lumbo-pelvic kinematics in people with and without back pain: a systematic review and meta-analysis. *BMC Musculoskeletal Disorders* 2014 15:1, 15(1), 1–13. <https://doi.org/10.1186/1471-2474-15-229>
- Lezin, N., & Watkins-Castillo, S. (2018). *The Burden of Musculoskeletal Diseases in the United States: Prevalence, Societal and Economic Cost*.
- Liebsch, C., & Wilke, H. (2021). The effect of multiplanar loading on the intradiscal pressure of the whole human spine: systematic review and meta-analysis. *European Cells and Materials*, 41, 388–400. <https://doi.org/10.22203/eCM.v041a25>
- Limbong, I. R., & Widajati, N. (2021). The Correlation between Body Mass Index and Lifting Frequency with Low Back Pain Complaints on Rice Transport Workers in Warehouse of Perum BULOG Subdivre Pematangsiantar. *Indian Journal of Forensic Medicine & Toxicology*, 15(1), 1168–1174. <https://doi.org/10.37506/ijfamt.v15i1.13576>
- Madeleine, P., Mathiassen, S. E., & Arendt-Nielsen, L. (2008). Changes in the degree of motor variability associated with experimental and chronic neck–shoulder pain during a standardised repetitive arm movement. *Experimental Brain Research*, 185(4), 689–698. <https://doi.org/10.1007/s00221-007-1199-2>
- Madeleine, P., Voigt, M., & Mathiassen, S. E. (2008). The size of cycle-to-cycle variability in biomechanical exposure among butchers performing a standardised cutting task. *Ergonomics*, 51(7), 1078–1095. <https://doi.org/10.1080/00140130801958659>
- Marras, W. S., & Karwowski, W. (2006). *Fundamentals and Assessment Tools for Occupational Ergonomics* (2nd editio). CRC Press Taylor & Francis Group. <https://doi.org/10.1201/9781420003635>
- Mathiassen, S. E., Burdorf, A., Van Der Beek, A. J., & Hansson, G. Å. (2003). Efficient one-day sampling of mechanical job exposure data—a study based on upper trapezius activity in cleaners and office workers. *American Industrial Hygiene Association Journal*, 64(2), 196–211. <https://doi.org/10.1080/15428110308984809>
- Mathiassen, S. E., Möller, T., & Forsman, M. (2003). Variability in mechanical exposure within and between individuals performing a highly constrained industrial work task. *Ergonomics*, 46(8), 800–824.

<https://doi.org/10.1080/0014013031000090125>

- Mehta, J. P., Lavender, S. A., & Jagacinski, R. J. (2014). Physiological and biomechanical responses to a prolonged repetitive asymmetric lifting activity. *Ergonomics*, 57(4), 575–588. <https://doi.org/10.1080/00140139.2014.887788>
- Nielsen, K., & Randall, R. (2015). Assessing and addressing the fit of planned interventions to the organizational context. In M. Karanika-Murray & C. Biron (Eds.), *Derailed Organizational Interventions for Stress and Well-Being: Confessions of Failure and Solutions for Success* (pp. 107–113). Springer Science + Business Media Dordrecht, Netherlands. https://doi.org/10.1007/978-94-017-9867-9_12
- Nunes, I. (2009). Ergonomic Risk Assessment Methodologies for Work-Related Musculoskeletal Disorders: A Patent Overview. *Recent Patents on Biomedical Engineering*, 2(2), 121–132. <https://doi.org/10.2174/1874764710902020121>
- O’Sullivan, P., Smith, A., Beales, D., & Straker, L. (2017). Understanding Adolescent Low Back Pain From a Multidimensional Perspective: Implications for Management. *Journal of Orthopaedic & Sports Physical Therapy*, 47(10), 741–751. <https://doi.org/10.2519/jospt.2017.7376>
- Oakley, P. A., Harrison, D. D., Harrison, D. E., & Haas, J. W. (2005). Evidence-based protocol for structural rehabilitation of the spine and posture: review of clinical biomechanics of posture (CBP) publications. *The Journal of the Canadian Chiropractic Association*, 49(4), 270–296. <https://doi.org/0008-3194/2005/270-296>
- Openshaw, S., & Taylor, E. (2006). *Ergonomics and Design. A Reference Guide*. © 2006 Allsteel Inc.
- Pałęga, M. (2019). Assessment of the physical load of the waterjet operator using the G. Lehmann method. *Multidisciplinary Aspects of Production Engineering*, 2(1), 101–107. <https://doi.org/10.2478/mape-2019-0010>
- Pistolesi, F., & Lazzzerini, B. (2020). Assessing the Risk of Low Back Pain and Injury via Inertial and Barometric Sensors. *IEEE Transactions on Industrial Informatics*, 16(11), 7199–7208. <https://doi.org/10.1109/TII.2020.2992984>
- Polga, D. J., Beaubien, B. P., Kallemeier, P. M., Schellhas, K. P., Lew, W. D., Buttermann, G. R., & Wood, K. B. (2004). Measurement of In Vivo Intradiscal Pressure in Healthy Thoracic Intervertebral Discs. *Spine*, 29(12), 1320–1324. <https://doi.org/10.1097/01.BRS.0000127179.13271.78>
- Richardson, K. M., & Rothstein, H. R. (2008). Effects of occupational stress management intervention programs: A meta-analysis. *Journal of Occupational Health Psychology*, 13(1), 69–93. <https://doi.org/10.1037/1076-8998.13.1.69>
- Roman-Liu, D. (2013). External load and the reaction of the musculoskeletal system – A conceptual model of the interaction. *International Journal of Industrial Ergonomics*, 43(4), 356–362. <https://doi.org/10.1016/j.ergon.2013.04.002>
- Schabracq, M. J., Winnubst, J. A. M., & Cooper, C. L. (2004). The Handbook of Work and Health Psychology: Second Edition. In *The Handbook of Work and Health Psychology: Second Edition*. John Wiley and Sons, Ltd. <https://doi.org/10.1002/0470013400>
- Shoaf, C., Genaidy, A., Karwowski, W., Waters, T., & Christensen, D. (1997). Comprehensive manual handling limits for lowering, pushing, pulling and carrying activities. *Ergonomics*, 40(11), 1183–1200. <https://doi.org/10.1080/001401397187432>
- Sinclair, R. R., Sears, L. E., Probst, T., & Zajack, M. (2010). A Multilevel Model of Economic Stress and Employee Well-Being. In *Contemporary Occupational Health Psychology* (pp. 1–20). Wiley-Blackwell. <https://doi.org/10.1002/9780470661550.ch1>

- Skals, S., Bláfoss, R., Andersen, L. L., Andersen, M. S., & de Zee, M. (2021). Manual material handling in the supermarket sector. Part 2: Knee, spine and shoulder joint reaction forces. *Applied Ergonomics*, 92, 103345. <https://doi.org/10.1016/J.APERGO.2020.103345>
- Snook, S. H., & Ciriello, V. M. (1991). The design of manual handling tasks: revised tables of maximum acceptable weights and forces. *Ergonomics*, 34(9), 1197–1213. <https://doi.org/10.1080/00140139108964855>
- Solomonow, M., Baratta, R. V., Zhou, B.-H., Burger, E., Zieske, A., & Gedalia, A. (2003). Muscular dysfunction elicited by creep of lumbar viscoelastic tissue. *Journal of Electromyography and Kinesiology*, 13(4), 381–396. [https://doi.org/10.1016/S1050-6411\(03\)00045-2](https://doi.org/10.1016/S1050-6411(03)00045-2)
- Soucie, J. M., Wang, C., Forsyth, A., Funk, S., Denny, M., Roach, K. E., & Boone, D. (2011). Range of motion measurements: reference values and a database for comparison studies. *Haemophilia*, 17(3), 500–507. <https://doi.org/10.1111/j.1365-2516.2010.02399.x>
- Srinivasan, D., & Mathiassen, S. E. (2012). Motor variability in occupational health and performance. *Clinical Biomechanics*, 27(10), 979–993. <https://doi.org/10.1016/j.clinbiomech.2012.08.007>
- Stubbs, N. B., Fernandez, J. E., & Glenn, W. M. (1993). Normative data on joint ranges of motion of 25- to 54-year-old males. *International Journal of Industrial Ergonomics*, 12(4), 265–272. [https://doi.org/10.1016/0169-8141\(93\)90096-V](https://doi.org/10.1016/0169-8141(93)90096-V)
- Swain, C. T. V., Pan, F., Owen, P. J., Schmidt, H., & Belavy, D. L. (2020). No consensus on causality of spine postures or physical exposure and low back pain: A systematic review of systematic reviews. *Journal of Biomechanics*, 102, 109312. <https://doi.org/10.1016/j.jbiomech.2019.08.006>
- Taibi, Y., Metzler, Y. A., Bellingrath, S., & Müller, A. (2021). A systematic overview on the risk effects of psychosocial work characteristics on musculoskeletal disorders, absenteeism, and workplace accidents. *Applied Ergonomics*, 95, 103434. <https://doi.org/10.1016/j.apergo.2021.103434>
- Teufl, W., Miezal, M., Taetz, B., Fröhlich, M., & Bleser, G. (2019). Validity of inertial sensor based 3D joint kinematics of static and dynamic sport and physiotherapy specific movements. *PLOS ONE*, 14(2), e0213064. <https://doi.org/10.1371/journal.pone.0213064>
- van der Windt, D. A. W. M. (2000). Occupational risk factors for shoulder pain: a systematic review. *Occupational and Environmental Medicine*, 57(7), 433–442. <https://doi.org/10.1136/oem.57.7.433>
- Waters, T. R., Putz-Anderson, V., Garg, A., & Fine, L. J. (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics*, 36(7), 749–776. <https://doi.org/10.1080/00140139308967940>
- Woodson, W. E., Tillman, B., & Tillman, P. (1992). *Human factors design handbook: information and guidelines for the design of systems, facilities, equipment, and products for human use*. McGraw-Hill Education.
- Wu, G., & Cavanagh, P. R. (1995). ISB recommendations for standardization in the reporting of kinematic data. *Journal of Biomechanics*, 28(10), 1257–1261. [https://doi.org/10.1016/0021-9290\(95\)00017-C](https://doi.org/10.1016/0021-9290(95)00017-C)
- Wu, G., Siegler, S., Allard, P., Kirtley, C., Leardini, A., Rosenbaum, D., Whittle, M., D’Lima, D. D., Cristofolini, L., Witte, H., Schmid, O., & Stokes, I. (2002). ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine. *Journal of Biomechanics*, 35(4), 543–548. [https://doi.org/10.1016/S0021-9290\(01\)00222-6](https://doi.org/10.1016/S0021-9290(01)00222-6)
- Wu, G., van der Helm, F. C. T., (DirkJan) Veeger, H. E. J., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A. R., McQuade, K., Wang, X., Werner, F. W., & Buchholz, B. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. *Journal of Biomechanics*, 38(5), 981–992.

<https://doi.org/10.1016/j.jbiomech.2004.05.042>

Yunus, M. N. H., Jaafar, M. H., Mohamed, A. S. A., Azraai, N. Z., & Hossain, M. S. (2021). Implementation of Kinetic and Kinematic Variables in Ergonomic Risk Assessment Using Motion Capture Simulation: A Review. *International Journal of Environmental Research and Public Health*, 18(16), 8342. <https://doi.org/10.3390/ijerph18168342>

Zhang, D., Mishra, S., Brynjolfsson, E., Etchemendy, J., Ganguli, D., Grosz, B., Lyons, T., Manyika, J., Niebles, J. C., Sellitto, M., Shoham, Y., Clark, J., & Perrault, R. (2021). *Artificial Intelligence Index Report 2021*.

Authors' Note

The project has been financed by the Ministry of Science and Higher Education in Poland under the “Regional Initiative of Excellence” programme 2019–2022, project number 015/RID/2018/19. The total funding amount was 10,721,040.00 PLN.

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Human Technology
ISSN 1795-6889
<https://ht.csr-pub.eu>

ARE YOU THERE? PRESENCE IN COLLABORATIVE DISTANCE WORK

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Abstract: *Already before the pandemic, digitally mediated collaborative work and communication were perceived as challenging. We investigate the attitudes towards emerging technologies and for transforming practises in workplaces. The focus lies on understanding the readiness for appropriating emotional tracking on presence and support for collaboration. The research-based design framework allowed to combine the various perspectives of the transdisciplinary team. Methods included participatory design, design thinking, contextual inquiry and prototype testing for enhancing presence while working with shared objects in video conferencing to explore the appropriation of tools. The findings revealed four indications: 1) awareness of interlocutors' presence during synchronous communication is crucial. 2) Emotion and behaviour tracking raises concerns about privacy and personal control over what is displayed to others, and technology could be simpler non-distracting the work at hand. 3) The prototype was found to enhance the feeling of presence without disturbing work at hand, and 4) appropriation requires a step-by-step approach.*

Keywords: *Research-based design, tracking, presence, computer-mediated communication, collaboration at work, distance work.*

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the Centre of Sociological Research, Poland
DOI: <https://doi.org/10.14254/1795-6889.2021.17-3.5>



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INTRODUCTION

Communication and collaboration through digital technologies are necessary aspects of almost all types of work. Not surprisingly, communication through digital technologies is still perceived to be unsatisfactory. For instance, it takes too much effort to make sense if the others are attentive and present, especially when the participants do not know each other well enough. Remote communication hinders collaborative work as participation in the work is not displayed evenly to all. (Hannola, Richter, Richter, & Stocker, 2018). The solutions thus far have not adequately solved the challenge of presence in a way that maintains concentration on the work.

Prominent perspectives into the subject can be grouped into a technology-dominant angle studying features which enable or support, for instance, participants' feeling of other participants' presence and practice, and an experience-dominant angle investigating requirements of how to support collaboration and communication during work. Various research areas, for instance, Human-Computer Interaction (HCI), Computer-Mediated Communication (CMC), Computer Supported Cooperative Work (CSCW), and cognitive neuroscience, have explored the challenges associated with digital communication and collaboration tools.

In this article, we approach the issues of presence, awareness, and support for collaboration from a transdisciplinary perspective. Our team consists of design researchers with expertise in co-design and design thinking, technology-enhanced work and learning research, and researchers in the field of cognitive neuroscience. Thus, the framework we use is broad, and it includes the fields of HCI, CMC, CSCW and cognitive neuroscience. CSCW has discussed various aspects of collaboration, from Grudin's (1994) group work and social dynamics to Stahl's (2016) recent studies on intersubjectivity and group cognition. CMC, similarly, has been digging into issues on digital, remote, and synchronous communication from Boon and Holmes (1991) discussing the dynamics of interpersonal trust to Biocca, Harms, & Burgoon (2003) on theory and measurement of social presence. HCI began with awareness features (Gutwin & Greenberg, 1998) and advanced into complex presence measures (Froese, Iizuka, & Ikegami, 2014), borrowing ideas from cognitive neuroscience. We also have first-hand experience designing some of the first awareness features into computer-supported learning and working in various international projects (e.g., Netpro¹). However, digital tools have improved, and research on how presence is observed and experienced, including topics such as the relationship between inter-brain synchronisation (Balters, Mayseless, Hawthorne, & Reiss, 2021), has increased recently. We complement the new neuroscientific findings by looking back and including research-based design studies to understand the current needs and attitudes in workplaces. It seems that we are in a paradigm shift on what learning and working means. This disruptive transformation is partially initiated by digitalisation – using emerging tools such as algorithmic systems that are proposed to be implemented in all parts of life. The pandemic has been accelerating this tendency (Trenerry al., 2021).

Our objectives for the research were to understand if there is a change in the hindrances of collaboration and communication in remote work due to the forceful introduction of emerged technologies and digitalisation. The workplace sectors were based on the Business Finland project HUMEX Quantifying Human Experience for Increased Intelligence Within

Work Teams and in the Customer Interface. Most sectors can be categorised as knowledge work, e.g., legal, insurance, development, design and marketing companies/customer services, and the construction sector at the decision-making level.

We used research-based design methods to investigate the current workplace hindrances and benefits of emerging technologies. The research-based design allows us to combine the different disciplines and real context on workplaces providing a thicker description of the current change, attitudes towards the new technologies and potential transformation of work cultures.

Our research is based on the hypothesis H1: *there is a need to use algorithmic systems on generating emotional and behavioural data for tools that enhance, support and scaffold the digitally mediated collaborative work*

During the research process, it became clear we had to narrow our hypothesis into (H2): *Simplify the tools used for collaboration in the work setting*

a) *the feedback of the presence of other interlocutors must be as simplified as possible so that it can be perceived at a glance or with peripheral vision and*

b) *the workers must feel that they are in control of what is presented to the other interlocutors.*

Next, we go through the previous research on the framework of HCI, CMC, CSCW and contrast these with current findings on cognitive neuroscience. We start with older research to build the background of what is known and could be used for new approaches. After which, we describe the methods, data collection and analysis. From there, we move to the findings and results.

BACKGROUND ON COMMUNICATION AND COLLABORATION THROUGH DIGITAL TECHNOLOGIES

This section discusses research that has allowed us to tackle new difficulties of appropriating new tools and practises for digitally mediated communication and collaboration.

The crucial features of digitally mediated communication are visibility of interlocutors' actions to guide interactions and seeing that others are present and available for communication, which affects communicative behaviours and accountability. Previous research has focused on improving turn-taking (Anderson, Beard, & Walther, 2010), enhancing situation-, work-, social- and self-awareness (Dourish & Bellotti, 1992; Gross, 2013) and identifying relevant non-verbal communication cues (Cameron & Webster, 2005; Kruger, Epley, Parker, & Ng, 2005) or on evoking affective interdependencies (Salminen et al., 2018). Part of the awareness is to understand that *I* and *others* are receptive to communication (Gutwin & Greenberg, 1998). Quan-Haase, Cothrel, and Wellman (2005) investigated online communication, and they explained the underlying needs for successful, digitally mediated communication and collaboration. The four needs are a) The interlocutors' task interdependencies, their history of collaboration and informal socialising support the success of communication during collaborative work; b) Visibility results in awareness when the interlocutors know each other or share experiences; c) Increasing social cues works well when the interlocutors are acquainted with each other and have established trust; and d) The roles the interlocutors possess make a difference: lower-status employees feel a need to answer timely, and higher status employees expect responses within a short time.

Recently, the focus has been on future technologies in HCI. Mueller, Maes, and Grudin (2019) referred to as Human-Computer Integration (HInt). The HInt is divided into three classes on their ability to provoke different types of awareness in humans: on-, off- and in-body. Off-body is technology situated in the environment around the body and is not physically attached to the body. The on-body is technology existing on the surface of the body (such as wearables or hand-held devices), and the in-body is a technology that exists internally within the body (such as ingestible devices) (Mueller, Maes, & Grudin, 2019). These technologies are seen to provide to their “wearers” various benefits; for instance, off-body provides the familiar sensor information for checking the weather, location, and speed. These are often used in recreational and work practises alike. The on-body technology may be most known by health applications such as monitoring sleep patterns, heart rate and blood sugar levels. Lastly, in-body technology is often unthought-of but well-known since it includes pacemakers, hearing aids, eyesight improvements, and new technology such as memory aids and stress management. All of these known so far aim to help, support and make life easier by knowing oneself and one’s behaviour, namely one’s habits. However, the arousal information is not often used for enhancing empathy or collaboration or for interpersonal communication, but monitoring stress levels, for being calm, strong, social and smart, for instance, with mental health smartphone apps (Bakker, Kazantzis, Rickwood, & Rickard, 2016; Peake, Kerr, & Sullivan, 2018).

Although many communication tools provide rich media such as emojis, audio and video notes, and video conference features, people still need to adapt their communication and work styles to the possibilities and limitations of what the current technology supports (Koskinen, Zimmerman, Binder, Redstrom, & Wensveen, 2013; Zhao, Lampe, & Ellison, 2016). As a result, achieving successful collaboration in workplace settings requires participants’ attention and effort to overcome technological limitations. According to well-known works of Trigg and Bødker (1994) and Schmidt and Bannon (1992), achieving better tools requires that the tools evolve with use, meaning the tools support appropriation, customisation and tailoring culture as well as provide affordances for adaptation. In this article, the interest lies in determining how attitudes towards computer-mediated interactions have changed for synchronous communication and collaboration in a work context and whether this knowledge can be used to co-design tools that evolve along with the use. It is relevant to ascertain how automated tracking of interlocutors’ behaviours and emotions can impact workers’ perceived use of computer-mediated communication tools. For instance, Dourish (2003) has aptly stated that tools change practises, and modified practises change what is expected from the tools, meaning that the tools and systems should evolve with use while being situated in the intersection of technical design and social practice. Therefore, the mismatch between the flexible, mutable and evolving practises contrary to the predefined, rigid, resistant tools creates a gap between the practises and technological possibilities, called the ‘socio-technical gap’ (Ackerman, 2000; Törpel, Pipek, & Rittenbruch, 2003). Wulf et al., (2015) underline that appropriation is a complex process, it takes long, and the practises undergo changes during the process. The complexity of the appropriation process is due to the many different societal levels where the newly designed artefacts connect to the known, and unknown social practises. Social practises are not abstract but embodied and routinised, which means the practises are intertwined with the environment and form habits (Wulf et al., 2015). Ramstead, Veissière, and Kirmayer (2016) described how normative practises built on

the immersive participation of the agent in a social context are seen to regulate joint attention and shared intentionality. Knowing the habits of action and context will aid in supporting appropriation because it allows us to design tools and scaffolding for changing the habits (Fiore & Wiltshire, 2016).

Due to the differences between what technology can do and how people act and develop practises, it is essential to investigate how people anticipate the future, what they expect from technology and what they feel that they are willing to appropriate to transform existing digitally mediated collaborative practises at work.

Considering the advances in emotion tracking technologies and the positive impact that these technologies are expected to bring, in this study, we explore the way potential users feel about emotion tracking tools in workplace contexts and what is expected from these technologies. One of these technologies to consider is the ones measuring arousal. Arousal tracking is in focus because it is increasingly integrated into the tools offered to workers. Arousal refers to a physiological state that denotes energy and activation, associated with being awake, alert and ready to respond. In the dimensional models of emotions, high levels of arousal are related to emotions such as surprise, while emotions such as sadness are associated with low arousal levels (Bhattacharjee et al., 2018).

Sensor-based technologies monitor arousal by collecting data on the changes in heart rate, blood pressure or skin conductance to estimate the level of alertness of a person's physiological states (Gravina, Parastoo, Ghasemzadeh, & Fortino, 2017). These are increasingly used in natural situations, for instance, to measure heart rate variability changes using T-shirt integrated sensors and visualisations of heartbeat (Wikström et al., 2021).

From previous research, one of the focus areas that we listed as potential is awareness, also called presence. The terms awareness and presence are sometimes used interchangeably. Awareness is divided into actions about the others involved, context, and content. Other areas emphasise the feelings or emotions, showing empathy, agreement, understanding and support for habit-forming or changing practises. The above areas can be tackled with various technologies, e.g., sensors and algorithmic systems, that have different intrusion aspects that previous and current technologies use. The novel technologies are thought to support work, and work practises (for instance, knowledge work and understanding the feelings of co-workers or clients). As the work sectors available for the research have various aims and practises, our first task was to narrow the scope by understanding the current situation and the envisioned future.

We present a case study that follows the research-based design approach to identify the main challenges that digitally mediated interactions have on synchronous communication and collaboration in work contexts. The following section will describe the process, methods, and analysis we used.

RESEARCH-BASED DESIGN: CONTEXTUAL INQUIRY, PROTOTYPING, DATA AND ANALYSIS

The study has three parts: part A contextual inquiry and getting acquainted with the previous studies for creating the design hypothesis (see Figure 1, empirical-study part); and part B, where prototypes are designed and implemented for testing the hypothesis (fig.1, prototyping). We have also outlined a beginning of the future study part C – appropriation,

where the actual use at workplaces is studied longitudinally. All three parts have many iterations of data collection and analysis.

H1: Initial research hypothesis was that *there is a need to use algorithmic systems on generating emotional and behavioural data for tools that enhance, support and scaffold the digitally mediated collaborative work*. Algorithmic systems can provide recommendations, suggestions and sometimes interpretations based on various data collections.

H2: *After part A, we had to simplify our hypothesis to be: Simplify the tools used for collaboration in the work setting*

H2 was divided into two parts:

a) *the feedback of the presence of other interlocutors must be as simplified as possible so that it can be perceived at a glance or with peripheral vision and*

b) *the workers must feel that they are in control of what is presented to the other interlocutors.*

Study part A explores whether and how tracking interlocutors' physiological affective and arousal states could improve computer-mediated collaboration and communication and what types of attitudes people have towards the new technologies. During part B, we developed potential prototypes with the participants based on the findings. At the beginning of part C, the design prototypes were tested with the participants from the companies. Drawing on the prototype testing, we propose the design implications that promote design decisions and chosen methods.

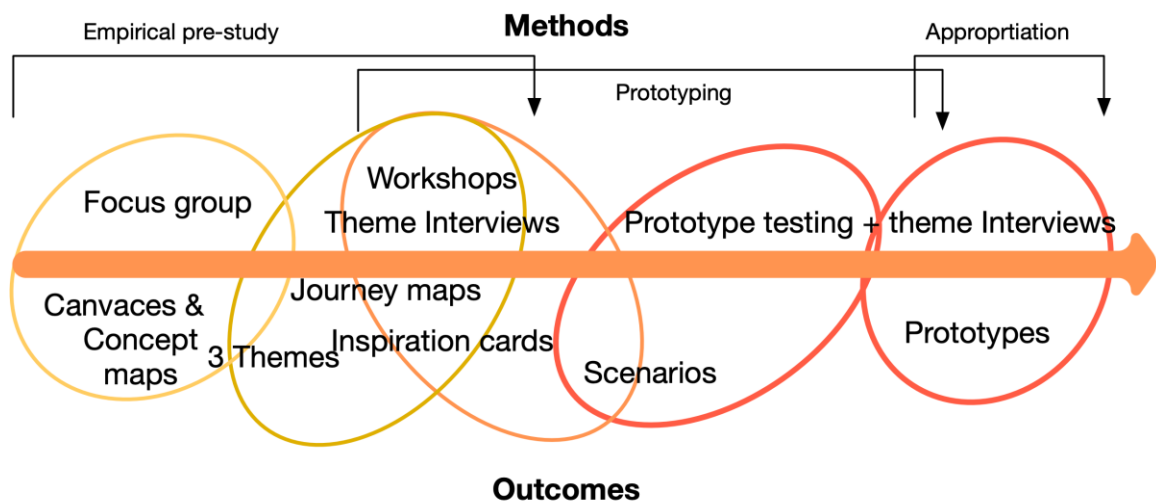


Figure 1. The figure presents the whole process of the design from contextual inquiry (part A), design, prototyping (part B) and a short study on appropriation, (part C) the methods used and the related outcomes.

We followed the constructive design approach (Koskinen et al. 2013) based on prototyping, frequent iterations, and encouragement for developing the prototypes (Mackay, 2000). The prototypes were developed iteratively involving representatives in all stages of the design process (Mattelmäki, 2006) for ensuring that digitally mediated communication and collaboration systems meet the participants' needs and researchers' aims. In particular, we adopted research-based design, which is influenced by co-design (Sanders, 2003) and the

user-centred design tradition (Stewart & Shamdasani, 2014). It is critical to involve artefacts called probes during the design process (Pirinen, 2016). Facilitators provide probes in focus groups and workshops to the participants, thus allowing them to express their expectations of digitally mediated collaboration challenges with tangible objects. Using artefacts early in the design process allows participants to try out and suggest potential usage practises. This practice enables us to detect the direction in which tools might need to evolve during actual usage. The process supports using empirically grounded conceptualisations (Wulf et al., 2015).

We selected the participants to represent different economic sectors such as software development, construction, marketing, insurance and advertising, and digital legal services. The companies' role was to provide a research context. The companies were future-oriented, executing knowledge work and using various digital tools. The selection of the companies' participants aimed to gather as wide as possible representative worker base covering various tasks from service, design, management, and execution. The selection was inspired by including extreme participants following the design thinking methodology. We sent messages or discussed with the company representatives to acquire the best variation between workers in each company). In total, we had 30 participants (16 female and 14 males, see Table 1).

Table 1. All participants in the contextual inquiry, prototyping and appropriation.

Sector	Female/male	Novice–expert
Design/marketing	7 females/ 3 males	full range
Development	3 females /5 males	full range
Insurance/customer service	4 females/ 4 males	full range
Legal services	1 female/ 1 male	leader/ expert
Construction	1 female/1 male	middle management / novice
Total	30	

Part A) Contextual and Empirical Research

During the design process of part: A) contextual and empirical research, we used various methods and techniques for prompting conversations about digitally mediated work challenges and attitudes towards emotional tracking in the work context. We carefully chose all the methods and techniques to provide in-depth and thick description knowledge from the field. As mentioned, the process was cyclic with data collection and analysis. The chosen techniques were observations, focus groups, workshops, and theme interviews to ensure that attitudes and practises could be made tangible.

In this phase, we facilitated two focus group sessions, four workshops, two interviews and background benchmarking were used to collect data. The data included video data, notes and design artefacts (see Table 2, and for the whole process, Figure 1). We investigated the attitudes towards emotion tracking, how the participants see it could enhance their work, current practises and what is not working at work when it comes to digitally mediated collaboration and communication. The focus groups and workshops were formed from different sectors. The focus groups allowed us to find overlaps in the work and attitudes. These were the guiding themes that directed the design of workshops and interviews.

The outputs of focus groups were then validated in workshops using inspiration cards and journey maps. The cards provoked discussion on tools in use, collaboration in distance

work, customer service challenges, communication issues, practises that work and do no work. We designed six cards in total (see Figure 3 for examples). Journey maps were on 1) Community building through instant messaging; 2) Showing engagement (presence) in an online focus group using video-conferencing (audio, no video); 3) Supporting shared understanding among groups using online video-conferencing (audio, no video construction field work² (see Figure 3 for example). These kinds of reused outcomes are called tangible outcomes and provide better iteration of the research process and design). In this part A, the participants came from insurance and legal service/company, development, design, marketing, and construction. Female and male division overall in part A. was 13 males and 14 females. The count does not add to 30 (see Table 1, where all participants of part A B C are counted) nor to the beyond 30 in Table 2 as some participants took part in more than one focus group or workshop. The number of participants is not enough to make broad generalisations but indicative suggestions for similar types of knowledge and service types of works. Through the methods and outputs, we answer to the

H1, there is a need to use algorithmic systems on generated emotional and behavioural tools to enhance, support and scaffold the digitally mediated collaborative work.

Table 2. Table 2 presents the methods, participants, data collection and analysis methods during the contextual inquiry (part A). The participant number does not add to 30 because some participants attended more than once to provide continuation.

Method	Participants	Length	Data collection	Techniques & materials used	Analysis methods
Focus groups (2)	Design/marketing (2), development (1) & construction (2) & insurance (1); legal company (1) people (7 on each workshop)	2 h	Notes, video & audio recording, outcomes of the activities	Synchronising practises (synchronous hand clapping), sketching and games	Qualitative analysis using design thinking techniques, such as canvases, templates and journey maps, to organise the data & artefacts. Spatial and physical organisation jointly by researchers belong to design thinking analysis methods
Workshops (4)	Design/marketing (1-2), development (1) & insurance (0-1); legal company (1) people (3-4 per each focus group)	2 h	Notes & video recording	Inspiration cards & scenarios	
Interviews (2)	Development (1) & insurance (1) company	1 h each	Notes & recording	Theme interviews	

Part B) Prototyping and Part C) Appropriating

Part B) prototyping and part C) appropriating included two different types of prototype testing. The setting of the prototype testing included two separate rooms where the workers were working on a joint document (shared artefact). Communication occurred through Skype or a similar audio/video conferencing tool. A randomly selected worker and student

participated in the first two prototype testing prototypes. Both were well-acquainted with video conferences and collaboration with co-workers/learners mediated by digital tools. One researcher was in one room in the first two prototype testing, and the worker/student was in another room. The participants could not see or hear each other directly. The document, or scenario, was described to the participant. The scenario described presented the challenges with a Skype discussion and collaborative work – named: Facilitating a focus group using video-conferencing (see Appendix 1). Overall, we had three scenarios to choose from (Facilitating a focus group using video-conferencing, Group discussion using audio-conference and Community building using instant messaging). Participants told which was closest to them). Both rooms and the screens of the researcher and the worker were video-recorded. One of the researchers observed the worker, taking notes and helping if the prototype failed to function correctly. These prototype testing aimed to determine whether The Noddors prototype functioned as anticipated and how the participants felt about it.

The first two prototype testing lasted an hour, and data was collected by observations, interviews and audio recording. These were transcribed and analysed by three researchers. The second two prototype testing were executed with real workers executing actual tasks. The workers came from digital legal services and marketing companies. The selection was based on the availability of a real collaborative online task. These lasted for one hour and a half. The workers were connected through their internal tool in different rooms and were working with an actual work document. The legal services workers were used to work on a joint document from distance offices. The collaborative tool for the shared document was the company's internal tool; however, in this setting, only half of the screen — the part where The Noddors was displayed — could be recorded because the document under discussion was classified. The second prototype testing with the marketing company followed the same setting, except the location was in the marketing company building. In both prototype testing, theme interviews, which were recorded, and during which notes were taken, were conducted afterwards. The themes of the interviews were the same as those of the first prototype testing.

The interviews were semi-structured, themed interviews. The themes were: the workers' feelings when using the Noddors, positive and negative feedback related to the concept of the prototype and its feasibility in real work and concerns and hopes of technology and improvements for the prototype. Three researchers analysed the data by comparing the lists of relevant comments from participants, videos, and notes. Important notes were highlighted and discussed to answer the hypothesis and considered for future development. The results cannot be generalised broadly but can indicate design directions for a similar collaborative work setting. The hypotheses were: a) the feedback of the presence of other interlocutors must be as simplified as possible so that it can be perceived at a glance or with peripheral vision, and b) the workers must feel that they are in control of what is presented to the other interlocutors.

The Analysis Methods of the Part A) Contextual and Empirical Research

The researchers from two universities analysed part A) contextual and empirical research in a design thinking manner using different canvases, templates and three journey maps (Biocca et al., 2003) to arrange the data in various ways and study them from multiple perspectives. We transcribed the focus groups, workshops, videos, theme interview audios and observation notes.

These were then sorted out into topics emerging from the data. The classification of relevant topics took three iterations. The researchers focused on physical and spatial arrangements of data to categorise them bottom-up. Spatial manner is supported in design thinking, providing tangible visual outcomes (for instance, the earlier mentioned topic descriptions canvases, inspiration cards, journey maps, scenarios) that can be reused to validate the outcomes with the participants in iterative manners. It is also one of the main ideas of research-based design (Mattelmäki, 2006). Such outcomes and work processes cannot be acquired when using digital tools such as Atlas.ti. Three researchers executed the primary analysis. The preliminary analysis of the process outputs was shared with four researchers from the project's partner universities to validate the analysis and provide a broader perspective. The process' outcomes of the focus groups led to canvases of classification and concept maps. These were summarised by the emerged themes (see Figure 2 a, b and c). Based on the previous outcomes, journey maps and inspiration cards were created for discussion with the participants. From the focus groups, workshops, and interviews, we had over 150 post-it notes. The data was analysed again by bottom-up note comparison between the researchers and categorised by emerging theme activities, context and tools. These provided the basis for scenarios to be used in prototype design. See the research team's outcomes blog³.

The concept of validity has been defined in various ways (Onwuegbuzie & Johnson, 2006). We followed the description of Teddlie and Tashakkori (2003), who see validity in qualitative research as inference transferability and inference quality. Inference quality is the identification of four evaluation criteria (a) within-design consistency, i.e., consistency of the design of the study and from which the inference emerged; (b) conceptual consistency is the degree to which the inferences are consistent with each other and with the known state of knowledge and theory; (c) interpretive agreement is the consistency of interpretations across people and (d) interpretations of the results and rival explanations are ruled out.

The Analysis Methods of Part B) Prototyping

The qualitative and thematic analysis of the part B prototyping was executed by comparing three researchers' notes and interpretations of the video recordings. For the analysis, we used triangulation in different researchers and data collection. The researchers transcribed the video recordings and digitalised the handwritten notes. After which, they listed the comments on the data. The prototype testing data were discussed, and similarities in the data were grouped in a similar spatial manner as in part A).

Business Finland supported the HUMEX project (Quantifying Human Experience for Increased Intelligence Within Work Teams and in the Customer Interface). The AALTO university's Ethical Review Board approved the study protocol. All participants signed written informed consent.

Section 4 describes the outcomes of the contextual inquiry and explains the choices made regarding the prototype to be designed with the participants. The findings indicated the need to narrow our hypothesis and simplify the prototype ideas.

FINDINGS FROM THE CONTEXTUAL INQUIRY (PART A)

After analysing the data from the focus groups (topics in focus groups: Facilitating a focus group using video-conferencing; Group collaboration using audio-conference; audio conference and Community building using Instant Messaging) where all the participants (insurance and legal service/company, development, design and marketing and construction sectors) were involved, the research team created a summary in the form of three themes – the topic description canvases. The themes recapitulate the most critical findings from focus groups' data (Fig.1). This outcome was a result of three (3) iterations. As a summary, the analysis revealed that people's awareness of interlocutors' presence during synchronous communication is a crucial need for successful collaboration, trust-building and shared understanding. These are difficult to establish in digitally mediated communications. Another finding was that the attitudes towards tracking arousal and the proposed interpretations of the state of the participants varied considerably. The arousal tracking was confusing to all except one participant. This one participant had executed festival micro-expression mapping from facial recognition of the crowd to the festival organisers. The others understood the arousal tracking to be data from facial recognition systems, owned or gathered by outside party sensory data. All of the above use algorithmic systems; thus, the hesitancy can be related to data use and accuracy of algorithmic systems and privacy.

The three canvases of the main themes are presented in Figure 2. We will summarise each one of them. We have not separated the outcomes by the workplace sector the participants represent because there was not that much variation between sectors; instead, variation occurred between individuals. Most participants were cautious of the new and emerging technologies. For us research designers, it was interesting to find out if the participants brought something new into the scene. Thus, we first summarise the participants' views, present some quotations from them and then provide a summary of already known challenges.

The bottom-up themes formulated to consist of a) presence – being able to feel the presence of others, b) trust – being able to build trust with others and c) shared understanding – knowing when shared understanding has been achieved. Below we summarise the findings using the above three themes from the focus groups. As mentioned, we focused on the H1 – topics of the attitudes towards emotion tracking, how the participants see it could be used to enhance their work, current practises and what is not working at work regarding digitally mediated collaboration and communication. The descriptions of the themes start with a summary of outcomes and quotations from the participants, relation to previous research (literature) to see if the participants came up with something not discussed before and what this means for future tools, and what we need to consider.

Presence

Summary

The participants explained presence⁴ as feeling the presence of the other interlocutor. This feeling may come holistically, or it can be sensed by one dominant sensory channel. Presence is essential in itself and as it enables knowing whether the other interlocutor is engaged in active listening. These formulations were used by the participants of the contextual inquiry (Figure 2 left side).

In this case, the tracking was understood as the system's default action, and attentiveness was presented based on the automatically tracked data. The participants wished to have control over what would be displayed for other interlocutors to see. Another concern was the system's amount of interpretation based on the data. For instance, it was mentioned that the system might interpret that one is not attentive and not present incorrectly due to personal differences that vary concerning the average of the measurements that are used by the system. The audio was mentioned as a way to understand presence.

Participants mentioning the audio/voice-related issues:

"Audio communications tend to be more "clinical" as people tend to make their comments and dialogue in a more condensed way. The conversation can be more straight, built is less rich than in F2F."

"Tone of voice, I have the image I do get the emotional involvement level view voice as well."

" But in big conversation it is the official voice. Lecture mode the one is group. Reporting situations are also that kind of non-emotional voice situations. "

"It is something common that in these contexts someone takes over, since these tools do not enable normal signs to show that you disagree, agree or so on, so giving this type of feedback is challenging. Voice is still is the only way to express yourself, even when there is video."

Other interesting statements from the participants related to tracking of expressions and control:

"In festivals analysis object and people - video-analysis for instance, XYZ festival, what people feel, micro-expressions - analysis of emotions and visible expressions for festival organisers."

"Feedback through other channels than video or audio – especially in the case of big presentations, would benefit from using other ways of sensing since this would allow keep eye contact."

"If the data tracked consists in a voluntary expression of people's mood, it is OK" Obtaining/giving feedback that is voluntary (like thumbs up, sending question marks...) – if it not verbal, e.g. thumbs up, down, nodding and so forth would feel comfortable.

"It's important to know beforehand if one is being tracked. Tracking could be beneficial as it re-inforce personal connection (presence?), help concentrating, performing active listening."

"Might be automated but I have the control and then I could do something, decide how the convey those signs."

"More control on how these data are conveyed"... "I prefer tracking at group level. "

"We want to have a good level of empathy in communications with customers– it it relates to the attitude of the person who is attending you, it is important that you feel that the other person really wants to understand your case "

There were few suggestions, but one caught our eye, which was about how to code the overall atmosphere: *"Colour coding if I am losing people overall feeling of the group."*

Previous Research

In the context of this design research, the concept idea of presence (related to awareness, see Biocca et al. 2003) consists of supporting different types of feedback, which allows for knowing the extent to which people taking part are present in a conversation or joint work mediated by digital tools. The array of tools that could provide this type of feedback changes according to the context, the conversation purpose and the type of presence that is being performed (Rogers & Lea, 2005).

Presence has also been connected to empathy, or the ability to understand the feelings of the other and the possibility to be present (Iacoboni et al., 2005). Recently, empathy has been defined as a skill that can be learned, even if it is still composed of different aspects, such as 1) experience sharing: vicariously sharing targets' internal states, 2) mentalising: explicitly considering (and perhaps understanding) targets' states and their sources, and 3) prosocial concern: expressing motivation to improve targets' experiences (for example, by reducing their suffering) (Zaki & Ochsner, 2012). Empathy can be viewed as part of the more frequently used definition of social presence (Sivunen & Nordbäck, 2015). Sivunen and Nordbäck (2015) defined empathy as composed of three aspects: a) co-presence, such as feeling inclusion or isolation and mutual awareness; b) psychological involvement, referring to mutual attention, empathy and shared understanding; and c) behavioural engagement, referring to behavioural interaction and dependent action. In this regard, social presence can be viewed as a group/team-level construct and observed in interactions between interlocutors.

Recently Grassini and Laumann (2020) executed a systematic literature review and brought up that only Lee (2004) has managed to provide some consistency into the concept of presence. Presence can be separated into three distinct domains: physical, social, and self. Physical refers to the experience of the physical environment and the objects within the environment, social directs to the experience of other entities with social value within the environment, and self-experience describes the experiences the user has of him/herself.

Meaning for Design

From the current research (Grassini & Laumann, 2020), it seems like the participants had reasonable suspicion since, so far, it is not possible to measure the feeling of presence accurately. The effects that the context has on the discussion, the role one has in the discussion, and the subject matter determine the amount of attention required to follow attentively. However, the participants also mentioned that if the data on presence would be acquired from the group activity where the information is anonymous, it might be acceptable (Quan-Haase et al., 2005; Sivunen & Nordbäck, 2015 on favouring group/team-level constructs). Thus, we may say that it can be accepted if it is general tracking and no persons can be detected. The suggestions and recommendations can be controlled by the users (participants). Being in control seems a valuable design feature as it is also often required by the algorithmic systems – having the human in the loop (Leslie & Briggs, 2021).

Shared Understanding

Summary

For the participants, shared understanding⁵ meant arriving at and knowing when there is an agreed understanding of a topic of discussion. The concept aims to provide tools for sharing and receiving information that will help detect whether people have a shared understanding of the topic under study (Fig. 2 middle). It was difficult for participants to determine what the system could track to help them understand that there is shared understanding. The participants requested cues for positive feelings and agreement, which they saw as supporting the building of the shared understanding. These feelings were more comfortable to digest than what the system displays about participants' feelings. Positive emotions are more natural to accept as the system's interpretation of what to present to other interlocutors, even without controlling what is displayed — some points made by the participants.

“Getting feedback about how well people are following/understanding could help adapt the speech (slow down or modifying the explanation).”

“Human touch” in their communications. It relates to the attitude of the person who is attending you; it is important that you feel that the other person really wants to understand your case.”

“We want to have a good level of empathy in communications with customers– it it relates to the attitude of the person who is attending you, it is important that you feel that the other person really wants to understand your case“

“We want to have a good level of empathy in communications with customers– it it relates to the attitude of the person who is attending you, it is important that you feel that the other person really wants to understand your case“

Human touch” in their communications. It relates to the attitude of the person who is attending you, it is important that you feel that the other person really wants to understand your case”

“Virtual object that you are touching together - shared something.”

“The more people get involved is through virtual objects, something you share with others. “An example of drawing - if members start drawing with me, this is a sign they are really interested and are willing to “buy” services/product. Therefore, making participation physical through a shared object contributes to increasing involvement.”

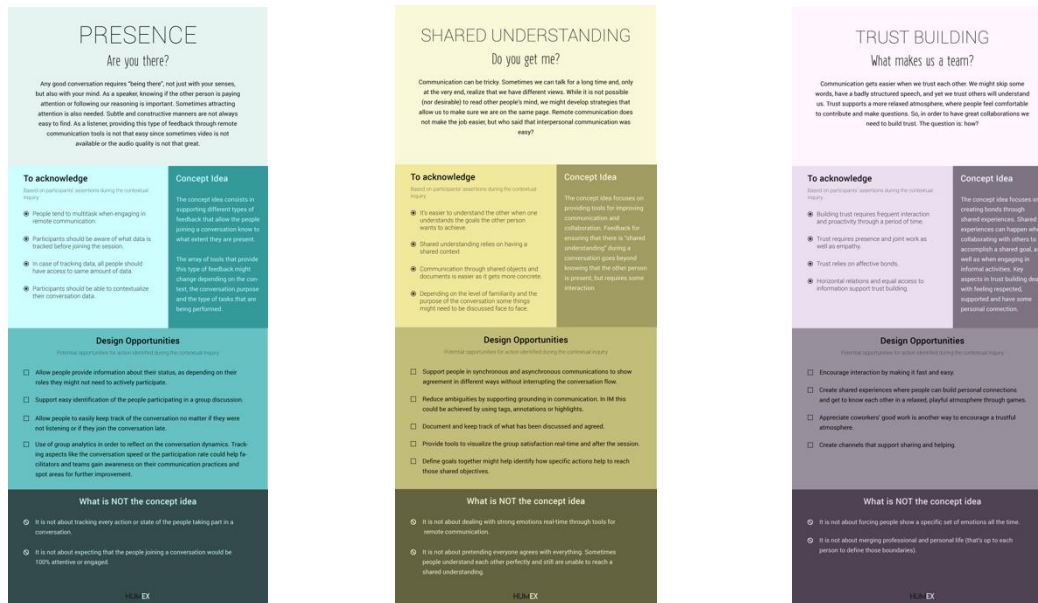


Figure 2. The themes as we presented them to participants for validation if we grasped their meaning well enough.

Previous Research

Shared understanding is a quintessential feature for successful joint and collaborative work practises, especially in the transition from dialogical practises to collaborative practises executed through shared artefacts (Paavola & Miettinen, 2019; Stahl, 2016). Most of the investigated work tasks were precisely these activities during which the participants were collaboratively and systematically developing shared, concrete artefacts together towards a common aim (see Appendix 1 on the scenarios drafted later in the process). A common ground ensures negotiation related to the shared artefacts (Clark & Brennan, 1991). In the work settings described by the participants, indexical signs were used to indicate tangible objects. These signs referred to actual occurrences and experiences familiar to those communicating to convey a meaning shared through similar experiences. The interlocutors share similar experiences through the common ground and correct and reshape the common ground during the conversation (Arrighi & Ferrario, 2008). Recently common ground supporting shared understanding has been researched within the scope of music interpretations (Schober & Neta, 2016). It means that the participants of the event augment the base for forming a shared understanding. The joint base of, e.g., experiences has also been referred to as 'anchored discussion' (Van der Pol, 2007). From the perspective of technologies, these should provide supporting affordances and cues for fluent and organised joint work with shared artefacts and practises (Bayer, Campbell, & Ling, 2015). The workshops' participants' thoughts were aligned with previous research exploring challenges for shared understanding, such as interpersonal differences, the absence of shared history and context (Hinds & Mortensen, 2005) and a lack of information related to the team members and tool ecosystems used (Bayer et al., 2015).

Meaning for Design

The participants generally mentioned sharing objects or doing things together as necessary. Thus, allowing collaboration focussed collaboration might support shared understanding. The other worries that arose were following the others, understanding if they are on the same page, or engaged, possibilities to show empathy. For design, it would mean enhanced means to collaborate without attention distracters. We could imagine that using other senses to detect the other participants' eagerness and ability to follow might provide some solutions.

Trust

Summary

According to the workshop participants, trust⁶ relates to feeling comfortable and safe and is associated with a relaxed atmosphere where it is possible to fail or express oneself poorly, such as forgetting words or using incorrect terms and incomplete sentences. We heard ideas such as: *“Critical to have is trust – there is no trust the system conveying in the right manner.”*

“Like when seeing people’s faces - problem in video-conf tools like skype is that people’s face icons are too small and it’s difficult to get that information) – depending on trust level, useful to get participants’ feedback (from 1 to 10) about how was their day – make the conversation more human and give useful feedback about the state (mood, involvement) of the person “

“Trust is also built by the company culture or let’s say the company culture has strong effect on how trust is built. It is not so much about horizontal or vertical company structure. The company needs to assists, acceptance agreement, raw data doesn’t help – needs to be aggregated.”

“Trust is not built by the coffee mate app (nor by giving “hugs”) but by actions. “

The concept emphasises creating bonds through shared experiences (Figure 2 right side). For two companies (marketing and design & development – fusion company), the aim was to build and maintain a more profound work culture of respect, appreciation and trust with a homely atmosphere. The participants expressed the need to maintain the homely feeling even when the companies grow by promoting interactions, such as organising meetings between different offices from different countries.

For example, a heartbeat without a system interpreting what the heartbeat means was more acceptable than when the system would present an interpretation of what an increase in a heartbeat might mean (below as one of the prototypes developed further and see Wikström et al., 2021).

Previous Research

A key aspect of trust-building relies on the feeling that one is respected and supported (Boon & Holmes, 1991). Personal connections might help develop trust, but they are not sufficient

(Preece, 2004). Kuo and Yu (2009) divided trust into three categories. The first is calculus-based trust in distant teamwork. Calculus-based trust emerges based on a member's assessment of the outcomes and costs of maintaining a group relationship. When a team continues to work productively, calculus-based trust transforms into knowledge-based trust (knowledge of others' competencies allowing the members to make predictions on each other's behaviours). Ultimately, identity-based trust emerges. It is grounded in the members' mutual identity and the willingness to support each other (Lewicki, McAllister, & Bies, 1998; Rousseau, Sitkin, Burt, & Camerer, 1998). Identity-based trust develops after the teams have worked together effectively for extended periods or at the end of the project. Järvenpää, Shaw, and Staples (2004) and McKnight Choudhury and Kacmar (2002) found that identity-based trust is dependent on the members' shared values and norms of obligations, and it allows members to support others.

Meaning for Design

For the current investigation, identity-based trust is attractive because the companies involved were attempting to build and maintain a particular work culture. The considerations on the trustfulness of technological actions come close to how the participants defined their suspicions as there is some risk of mistakes technology may make. However, although the participants had these concerns, they were optimistic that the new technologies would help people be more empathic and supportive towards each other in the future.

To answer the H1, *there is a need to use algorithmic systems on generated emotional and behavioural tools to enhance, support and scaffold the digitally mediated collaborative work*; we can answer yes. There is a need to use algorithms but not necessarily for suggesting, recommending or providing interpretations of emotions or behaviours. Subtle ways of positive emotions (such as agreement, following, empathy, and understanding of the topic under discussion) were seen to bring positive outcomes. In addition, voluntary feedback presentation – the need to control what is presented and how was another topic of discussion. Tentatively, we could summarise that small attempts towards new technologies were supported, and despite the concerns, there was optimism about the future.

Journey Maps, Inspiration Cards and Next Steps

After reviewing these three themes in the light of previous research and discussing them with the workshop participants, the journey maps were developed. The journey maps helped obtain a better understanding of the interactions between the actors, tools and the ecosystem where the communications and collaborations occurred. The themes and the journey maps: Community building with instant messaging, Showing engagement (presence) in an online focus group using video-conferencing (audio, no video), Supporting shared understanding among the group using online video-conferencing (audio) (see Figure 3 right for an example) provided relevant insights that informed the creation of scenarios: Facilitating a focus group using video-conferencing, Group discussion using audio-conference and Community building using instant messaging (see Appendix 1) and inspiration cards (see Figure 3 left).



Figure 3. Inspiration cards that encouraged people to think about the challenges related to digitally mediated communication and collaboration (left) and journey maps describing the process of actions are physical, spatial and tangible intermediate research output.

The scenarios presented different experiences with digital tools connected to community building using instant messaging, group discussions using audio-conferencing and facilitating a focus group using video-conferencing with shared artefacts. The researcher presented the scenario at the beginning of the workshop to introduce the theme and provide a concrete example similar to the participants' experiences with CMC and collaboration in the workplace regarding the challenges associated with specific tools. The feedback collected from the interviews and workshops using the inspiration cards and scenarios elucidated that the notion of presence was felt to be the most central aspect of the study. The workshops and interviews underlined again the difficulty of showing negative emotions or the care that these should be expressed constructively:

"Negative feelings can be expressed alone in virtual situations and you can still" look professional."

"Constructive fear, frustration, anger, personal antipathy - sometimes yes good to show, If there is trust, it works, but in the customer meeting - sometimes I even reflect."

"Presenting individual feelings ... No. 70% frustrated - but as group level you get the feelings"

"Shared a thing all of the group feels it - atmosphere."

"Constructive way to express is needed, group level, maybe from tone of voice and posture, positive things spread, a negative spiral can be spread by one person."

"Anonymous positive feedback to colleagues creates the bonus system."

2Perhaps this would not be a good idea if everyone gets same emotional info, possibility to fake, plus loss of control because one ends following the system instructions."

The participants mentioned that when feelings and emotions, such as agreement and disagreement, are presented in a manner that simulates a face-to-face situation as closely as possible, it is ineffective. These simulated situations require too much concentration in a digitally mediated context to be fruitful. Therefore, for efficiency during work tasks, it is essential to perceive agreement and attention easily.

"Technical quality seamless quality"

"Challenge in remote communications: the more people join the communication, the more info (audio, audiovisual) is coming in and that's difficult to handle from the technical point of view."

“This type of video conferencing without the video doesn't add anything and it is just like a phone call. On top of that chat is used for common discussion or notes. In a collaborative session like this someone is sharing their screen (who is leading the meeting) and the rest look at that, not faces. Its is easier to see, show screen then explain verbally. “

“In F2F it's easier to find out that the other person is lost, and thus he can adjust (move to a plan B), whereas in remote communication systems noticing is not that easy that the other person is lost.”

“Nodding is helpful in conversations, but it is not; it is used if it has to be done on purpose (both considered emoticons in 'skype' are useful, but somehow they are not that used or might be awkward to use if there is not much confidence.”

“Communication over a shared object happens almost all the time– it keeps the communication focused.”

In addition, the display should be straightforward, so it does not disturb actual work. These outcomes directed us to redefine the hypothesis into a narrower scope, and we had to dismantle complex tools ideas for this study to allow appropriation (Dourish, 2003).

Based on the journey maps and scenarios, various prototypes were created. In the HUMEX project's seminar, we presented prototypes created by students. There were two prototypes on voice, communication on shared work support – Nodders and customer service. Twelve participants (unanimously) selected the heartbeat customer service and the Nodders to be continued (see the finalised presentation of the prototypes in Appendix 2). The rest of the prototypes were completed as far as the student teams needed for their grade. The seminar allowed participants to try out the prototypes to understand them better. The student developers and designers were present to answer questions. The heartbeat visualisation for customer service development can be read from Wikström et al. (2021). Both selected prototypes allowed a step-to-step development towards different usage of technologies.

The Nodders prototype explores the challenges associated with the notion of presence. It aims to improve collaboration by providing non-verbal feedback regarding head gestures as an addition to the audio or video communication channel. During the design process, another factor was considered – a tool should evolve over time and with use (Arias, Eden, Fischer, & Gorman 2000; Wulf et al. 2015). The Nodders prototype is meant to be used in an audio or video conference.

Currently, the prototype consists of sensors attached to a headband, which reacts to the nodding of the wearer (see Figure 4a and b). The action is rendered close to real-time and is displayed as an animated nodding or shaking of the smiley on a computer screen visible to the participants on the conference call. The prototype design is minimal and uncomplicated to provide the interlocutors with feedback that is easy to process and perceived with peripheral attention (Carroll, Rosson, Farooq, & Xiao, 2009). The literature does not often mention this, but simplicity in collaborative technologies is vital for success. For instance, Nardi and Miller (1991) conducted a study that showed that effortless technologies designed as collaboration tools have proven to be most effective in encouraging collaborative work. These technologies succeed because they allow a smoother involvement with the use (Arias et al., 2000). The decision to reduce possible sensor-based features was difficult because many ideas related to tracking arousal that could have been designed and developed were abandoned. We dropped

out the idea of gaze following (see Pöysä-Tarhonen, Awwal, Häkkinen, & Otieno, 2020) and facial or micro-expression detection (Zhao & Li, 2019) because of the need for more technology to be added into the participants' use. In addition, to avoid such data collection from the participants, they could not control. The Noddors use algorithms to learn the nodding of the person wearing the sensor. Because people nod in different manners, some nod heavily and others lightly, but the participants still control the nodding. Thus, the use of the algorithmic system is minimal, and it is not providing suggestions or recommendations. We could say that it tries to interpret the nodding of a person.

To date, four prototype testing with workers were performed to attain iterative and frequent feedback that informs further development cycles. The first two prototype tests were carried out with simulated tasks. The second two with actual tasks shared artefacts and workers from two companies that participated in the previous focus groups. Next, the findings are described.

THE NODDERS PROTOTYPE TESTING AND DATA COLLECTION

Analysis of the prototype testing

During the first observations, it was difficult to recognise when the workers and the students noticed the smiley. The first impression was that they ignored it; however, during the interviews, the workers and the student mentioned that they were glancing at the smiley when it nodded. They also expressed that they saw the smiley in their peripheral vision because the movement was detectable as the smiley was otherwise still (Figure 4). For instance, participants stated: *“Usually, concentration on another’s presence takes effort. This takes it away from the joint work at hand. Now, I just saw it from the corner of my eye, or I saw it for a moment. That was enough because it only nods or doesn’t. I do not need to concentrate on the expression.”*

Similar comments were expressed after the prototype testing with workers from companies. In addition, when observing the second testing, it was easier to notice when the workers reacted to the smiley. The ability to observe better could be due to the researchers learning to pay attention to particular reactions (e.g., small head movements and pauses⁷) after the first two prototype tests.



Figure 4. Left side (a): The different stages of smileys on different participants (4 on this side of the image) – the two smileys on the left are in the nodding process, the second from right is neutral, and the far right is in the process of shaking the head. In the video, you can see the state of the neutral and nodding and a development phase sensor testing⁸. On the right side (b), the current sensor in the headband for detecting nodding. On the screen, you can see two smiles, two taking part in the conversation.

The workers and the student mentioned that the Noddors would improve their work and study. They explained that even though the video is available in the conferencing tool, they do not use it because interpreting cues from faces in a small video takes concentration away from the joint work. For instance, the following was expressed: *“Too detailed display would be horrible. I do not want to see myself in that much detail. A smiley is better—more neutral; video is too up front.”*

In addition, technological obstacles are still frequent. For instance, wireless connections are insufficient, and the video is not displayed well. The workers and the student stated that the delay in a video is more disturbing than it is in the smiley. The participants also mentioned they saw the smiley at a glance. For example: *“There should not be too many cues or too much noise. The smiley was fast and easy to see.”*

The slight delay was irrelevant because they had received the feedback that the interlocutor was attentive, while during a video, one must concentrate on seeing it well. Thus, one must shift continuously back and forth from the shared artefact to the video. The smiley was perceived to be simple enough not to take too much screen real estate, which is essential when the work at hand requires most of the screen space. One participant stated: *“I liked it because it is simple, fast to see and fits into the screen space without taking space from work, it reduces the technologies I use, or so I feel.”*

Furthermore, the participants pointed out that they did not feel intimidated because the system tracked their head nodding. It was felt to be the action that they wanted to express. With the smiley, attention was made visible, but physiological measures were not exposed to interpretation, which might happen with emotional tracking. The most interesting of the statements was: *“Seeing the smiley move made me nod more, and it reminded to give feedback to the co- worker that yes, I am hereco-workerning.”*

All stated that they might not need the shaking of the smiley's head to indicate that the interlocutor disagrees. The shaking smiley was viewed as unnecessary and confusing. If there is a disagreement, they most likely should discuss the issue. For instance, a participant mentioned: *“Positive emotions are good to see. Negative ones are not. One has to prepare to express the negatives correctly and constructively. Otherwise, it may escalate and become out of hand.”*

Most (5/6) also stated that if there were many participants, the smileys would need a different colour or something visual to distinguish the workers from each other. Another issue that needs to be resolved is the attachment of the sensor to the headset. Currently, it is attached to a headband due to the state of the prototype (Figure 3 b). The workers and students suggested that the sensors could be integrated into a headset, which they use when communicating using digital tools; moreover, they also stated that the headband was not an issue: *“The headband did not bother me. I am so used to headsets, which I use daily at work, that I did not notice the headband after a few seconds.”*

This study provided an indication of confirming both of the hypotheses: a) The smiley is simple enough to be perceived at a glance with peripheral vision. The shaking of the smiley's head will be eliminated so that it is even more straightforward and allows a design for distinguishing between many workers. b) Being in control of what occurs was also confirmed. The smiley promoted control in providing feedback to other interlocutors better than a typical Skype audio call. Another indication of a successful design direction and potential appropriation is that the companies wished to continue the prototype development.

DISCUSSION

Implications of Designing Tools for Supporting Presence in CMC and CSCW at Work

Based on the contextual inquiry findings and the prototype testing results, we describe some practical implications for the design of digital communication and collaboration tools that track data regarding the interlocutors' emotional states to increase the feeling of presence. Issues related to the attitudes of tracking arousal and potential for appropriation at work. This topic was pressing among the forerunners already before the COVID-19 pandemic, and now it is a central issue, especially in knowledge work. In addition, the number of devices that track physiological data has increased, and many are in some use already (Peake et al., 2018; Wikström et al., 2017; Gravina et al., 2017). Furthermore, the need to solve the still existing problems related to the presence, shared understanding and trust with these kinds of tools has been presented as part of the digitalisation process (Garro-Abarca, Palos-Sanchez, & Aguayo-Camacho, 2021).

Our hypothesis: *there is a need to use algorithmic systems on generating emotional and behavioural data for tools that enhance, support and scaffold the digitally mediated collaborative work*, was explored through readiness to accept new technologies, attitudes towards physiological data tracking and aspects of successful remote work. We found some surprising results and well-established essential factors for digitally mediated collaboration and communication at work.

Attitudes on tracking physiological states

First, people's readiness to accept the tracking of their physiological states, such as arousal levels, depends on myriads of factors connected to age, culture, work position, values and attitudes, and their familiarity with tracking technologies. Design implications derived from these observations deal with the anonymity and privacy level that the tools enable. For instance, people might feel comfortable with group activity tracking provided the information is kept anonymous but feel uncomfortable if the tracking takes place at the individual level. Additional implications involve providing clear information and obtaining consent. It means that the appropriation has started, but it is not well supported, as stated by Ingusci et al. (2021) on job crafting, which is well in line with the previous studies on appropriation (Ramstead et al., 2016).

Attitudes on readiness to apply

Second, people dislike being unable to control the data that the system monitors of their physiological states. In other words, people want to control the physiological data that tools display in visualisations to others and the machine interpretation of these data as it might affect the relationship with their counterparts (Noble and Roberts, 2016). Furthermore, there was a clear difference between negative and positive feelings. Negative feelings were felt to be private and should only be presented to others by the participant and not by the system. In

contrast, positive feelings can be presented to others as long as the participant is aware that this occurs. It supports maintaining cohesion (Garro-Abarca et al., 2021).

Direction of design for successful CMC and collaboration at work

Third, in the design direction, the research participants confirmed the importance of knowing that the interlocutors are present and engaged in active listening as being essential. It became apparent on the described current practises and the suggested scenarios that we used with the participants. Such scenarios were the digital tools connected to community building using instant messaging, group discussions using audio-conferencing and facilitating a focus group using video-conferencing with shared artefacts. Interestingly, being present did not mean that the interlocutors needed to be continuously monitored during the conversation, which was further tried out with The Noddors. In other words, a feeling of continuous presence is not necessary, but perceiving a useful presence is. In addition to presence, trust and shared understanding were mentioned, as Ingusci et al. (2021) also stress.

The Noddors prototype

The second hypothesis for enhancing presence with sensor-based tools that track voluntary physiological acts was tested. The hypothesis was that *a) the feedback of the presence of other interlocutors must be as simplified as possible so that it can be perceived at a glance or with peripheral vision, and b) the workers must feel that they are in control of what is presented to the other interlocutors*. During the participatory workshops and prototype testing, it was possible to conclude that tools for tracking presence can be distracting and, therefore, counterproductive if it increases cognitive overload (Ingusci et al., 2021). In this regard, it is vital to identify ways to provide feedback regarding a useful presence using peripheral attention. It also means there might be a reason to reduce technology and not add more. Sivunen and Nordbäck (2015) found a similar tendency in the virtual work environment research. The avatars played a minor role in creating a social presence during virtual team meetings in their study. The team members did not control the avatars. Controlling the avatars was too time-consuming concerning the focus on the subject and the aim of the meeting itself. In research on simulation fidelity at work training context, Hontvedt and Øvergård (2019) found that when in training, if the learning collaboration objectives are problem-solving strategies, mental models and feelings (psychological fidelity) and coordination and collaborative patterns within a team (interactional fidelity), high technical fidelity was not required but fidelity in reaching closely same feeling or collaborative patterns, often by reducing technology, e.g. by role-playing was required.

In this research study, the smiley was sufficient; it maintained concentration on the actual joint work, which was modified through the shared artefact. In addition, the animated emoji promoted the participants to nod more than usual during the work to maintain the attentiveness of the other empathy (Sivunen & Nordbäck, 2015; Zaki & Ochsner, 2012). Remarkably, one of the essential issues is a simplification. However, it is not about abandoning technology but pointing to the essential features of technology that support the correct issues at work and not offering all possible features available or keeping the ones that are hindering or unnecessary for the work (Garro-Abarca et al., 2021).

CONCLUSIONS

The research-based design has been prominently used in design research of tools for enhancing communication and collaboration (Bauters, Purma, & Leinonen, 2014; Pejoska, Bauters, Purma, & Leinonen, 2016). It has benefits such as the emphasis on hypotheses, theory-rich designs and allowing time for reflection on designs. It also supports the continuous critical revision of the research hypothesis. In the context of this research, some of the early hypotheses were related to the potential technologies to track interlocutors' physiological affective and arousal states, such as emotions. The expectation was that visualising data related to interlocutors' emotions enriches communication by increasing the feeling of presence, shared understanding and trust. The hypothesis (H1) was modified after the contextual inquiry to be more specific and to consider the participants' attitudes towards tracking emotions, which were positive in general but critical regarding what is displayed and how it is displayed to whom. Namely, a) tools must respect the interlocutors' control over them in addition that b) presenting negative emotions should always be under the complete control of the worker.

The Nodders prototype testing hypotheses were: a) The nodding smiley is simple enough to be perceived at a glance with the peripheral vision and b) Being in control of what is interpreted and displayed by the system. Both hypotheses were confirmed in the prototype testing. However, since this study was qualitative and we had six participants in the prototype testing, the results cannot be generalised. However, they can provide a base for further testing, especially in other collaborative work settings than the current setting. The Nodders prototype testing participants provided a significant advantage as they were willing to try out during actual work tasks in natural work environments. One of the prototypes testings' important insights is related to the current use, but insights also arose related to the next steps for the tools to evolve with the users. The hesitance of transforming practises requires step by step appropriation or well organised bottom-up support for the workers to accept a new form of work culture. These prototype testing furnished the research with a glimpse of possible appropriation of The Nodders into work use and how it might change the work practises, which we could not have had in case we had only simulated games in a laboratory setting or with student participants (Järvenpää et al., 2004; Kiesler, Siegel, & McGuire 1984). The Nodders was the first step in the appropriation.

The most crucial feature of enhanced presence is that it does not disturb concentration on the joint work. It means that much effort has to be invested in adapting to the current tools to focus on the main things – the actual work at hand. Thus, when designing new tools with emergent technologies, building the new tools on top of the old ones should be avoided, as this adds excess noise into digitally mediated collaboration at work. In our understanding, it means that bottom-up support is needed for scaffolding the appropriation of new tools and, if possible, reducing the old tools. Since the emerging technologies allow so many different types of collaboration that their actual value may be lost when mixed with the old tools, the best approach might be to start from scratch. However, the more significant the change is in working practises, and culture, the more robust support is needed (Ingusci et al., 2021). It was visible through the reluctance of the workers to try out with the dismantled prototypes of recognising emotions from live audio, deep learning on concepts used during discussions,

using face recognition to detect emotions in video conference collaboration had to be discarded from further prototyping.

The design-based research allowed the integrating of previous and current research from different disciplines. This broad and longitudinal view showed that the same challenges that were new in the 90s on digitally mediated work still exist. The themes of presence, trust, and shared understanding persist. We suggest that more interdisciplinary research is needed and thinking outside the box to solve these challenges. In addition, there is a global need to design beyond user-centric research. For instance, Feenberg (2010) pleads for reflections on the ethical aspects related to the responsibility of designers when developing tools. The limits of user-centred approaches are questioned as they might not be sufficient for dealing with complex and fast-changing systems (Törpel et al., 2003). Designers must consider the broader system in which the design takes place and consider the impact on the work culture and environment (Bauters, 2017).

Future Research Needs

The appropriation of The Noddors should be investigated because it provides a view on appropriating new concepts, practises and tools into the work context. It was also mentioned by the enterprises taking part in the Noddors prototype testing that they will continue the development. Thus, there is a context for further research. Future research might focus on, for instance, whether nodding might be replaced with eye tracking for measuring the presence or with some other physiological manner which is not found to be invasive, and if the attitude what is invasive will change and how (see also Pöysä-Tarhonen, Awwal, Häkkinen, & Otieno, 2020).

Currently, the pandemic is teaching many issues to us and directing us towards future research on the balance that could be found between face to face and digitally mediated communication and collaboration at work.

The Limitations of the Research

The study's limitations consist of focusing on a specific group of participants. The workers were selected from the companies which are forerunners in technology use, have resilience towards change, and are executing asynchronous and synchronous distance work. These workers are early adopters, well-aware of emerging technologies, and willing to transform their work practices. In addition, the number of participants is not large enough for generalisation. However, the contextual inquiry and prototyping length were long (18 months), so sustained research was possible with the same participants. Having the same participants in the study is a merit but also limits the variations or statistical analysis of the data. The highly interdisciplinary research team and framework can be seen as problematic because concepts, methodologies and analysis methods are hard to fit together, not to mention to follow by others or replicate it. The qualitative research-based design might have been difficult to digest. Since this research tradition tends to be descriptive, and case studies are emphasised, providing flesh to the research but reducing the ability to provide hard facts that can be used directly in other contexts. In our view, the topic we covered was missing this descriptive view and the different insight provided in it.

IMPLICATIONS FOR RESEARCH, APPLICATION, OR POLICY

The benefits of this research can be seen in the problematising the current user- and human-centric design methods, which cannot consider the longitudinal, nor the whole implications of the tools introduced to the tool ecosystems or as a part of the technology, society and environment ecosystems. We suggest increasingly interdisciplinary with a global perspective going beyond user-centric research to solve these challenges. For instance, future design and research need reflections on the ethical aspects that the tools can create and implications these tools have on habit changes (societal changes) and environmental biodiversity. Designers, researchers, citizens, participants must consider the broader system in which the design takes place and consider the impact on the work culture and environment (Bauters, 2017). We propose pondering using the system-centric view, deriving from Latour's (1999) actor-network theory.

On a more pragmatic scale, this research provides guidelines and ideas on reducing technology for better attention and concentration on the actual tasks at hand in collaborative work situations.

ENDNOTES [NOT FOOTNOTES]

1. <https://cordis.europa.eu/project/id/9727020>
2. The construction field work case is not described here in more detail, because their need was different. Related to communication and shared understanding but on understand various languages and especially construction slang in the different languages used.
3. <https://processingevidence.tumblr.com/>.
4. Theme presence:
https://66.media.tumblr.com/d0113b5bf8434b167164ed141464e22c/tumblr_p7hvkc16FG1xpkiro3_1280.png
5. Theme shared understanding:
https://66.media.tumblr.com/f16759c0edc9d22575172451b33aa289/tumblr_p7hvkc16FG1xpkiro2_1280.png
6. Theme trust:
https://66.media.tumblr.com/da30d0de8a1e4e2f7f88164d14975597/tumblr_p7hvkc16FG1xpkiro1_1280.png
7. We are aware that nodding is not a sign of agreement in all cultures, but for the first prototype and in our culture, it was enough to try out with the idea of detecting head gestures for agreement in distance collaboration at work.
8. Link to the video on the sensor in a headband:
<https://processingevidence.tumblr.com/post/172855322678/first-look-of-the-nodding-prototype-a-device-that>

REFERENCES

- Ackerman, M. S. (2000). The intellectual challenge of CSCW: The gap between social requirements and technical feasibility. In J. M. Carroll (Ed.), *Human Computer Interaction in the New Millennium*, (pp. 303–324). New York: ACM Press.
- Anderson, J. F. Beard, F. K., & Walther, J. B. (2010). Turn-taking and the local management of conversation in a highly simultaneous computer-mediated communication system, *Language@ Internet*. 7(7).

- Arias, E., Eden, H., Fischer, G., Gorman, A., & Scharff, E. (2000). Transcending the individual human mind—creating shared understanding through collaborative design. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 7(1), 84–113.
- Arrighi, C., & Ferrario, R. (2008). Abductive Reasoning, Interpretation and Collaborative Processes. *Foundations of Science*, 13, 75–87.
- Bakker, D., Kazantzis, N., Rickwood, D., & Rickard, N. (2016). Mental Health Smartphone Apps: Review and Evidence-Based Recommendations for Future Developments. *JMIR mental health*, 3(1), e7. <https://doi.org/10.2196/mental.4984>.
- Balters, S., Mayseless, N., Hawthorne, G., & Reiss, A. L. (2021). The Neuroscience of Team Cooperation Versus Team Collaboration. *Design Thinking Research: Interrogating the Doing*, 203.
- Bauters, M., Purma, J., & Leinonen, T. (2014). In-time on-place learning. In *10th International Conference on Mobile Learning 2014*, (pp. 256–260). IADIS Press.
- Bauters, M. (2017). Experience in Design and Learning Approaches—Enhancing the Framework for Experience. *Revista Română de Comunicare și Relații Publice*, 19(1), 51–68.
- Bayer, J. B., Campbell, S. W., & Ling, R. (2015). Connection Cues: Activating the Norms and Habits of Social Connectedness. *Communication Theory*, 26(2), 128–149. <https://doi.org/10.1111/comt.12090>
- Bhattacharjee, T., Datta, S., Das, D., Choudhury, A. D., Pal, A., & Ghosh, P. K. (2018). A Heart Rate Driven Kalman Filter for Continuous Arousal Trend Monitoring. In *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, (pp. 3572–3577). (EMBC), IEEE
- Biocca, F., Harms, C., & Burgoon, J. K. (2003). Toward a more robust theory and measure of social presence: Review and suggested criteria. *Presence: Teleoperators & virtual environments*, 12(5), 456–480.
- Boon, S. D., & Holmes, J. G. (1991). The dynamics of interpersonal trust: Resolving uncertainty in the face of risk. In R. A. Hinde & J. Groebel (Eds.), *Cooperation and Prosocial Behavior*, (pp. 190–211). Oxford, K: Basil Blackwell.
- Cameron, A. F., & Webster, J. (2005). Unintended consequences of emerging communication technologies: Instant messaging in the workplace. *Computers in Human behavior*, 21(1), 85–103.
- Carroll, J. M., Rosson, M. B., Farooq, U., & Xiao, L. (2009). Beyond being aware. *Information and Organization*, 19, 162–185. <https://doi.org/10.1016/j.infoandorg.2009.04.004>
- Clark, H. H., & Brennan, S. E. (1991). Grounding in communication. In L. B. Resnick, J. M. Levine, and S. D. Teasley (Eds.), *Perspectives on socially shared cognition*, (pp. 127–149). Washington, DC: APA Books.
- Dourish, P., & Bellotti, V. (1992). Awareness and coordination in shared workspaces. In *Proceedings of the Conference on Computer-Supported Cooperative Work*, Toronto, 107–114.
- Dourish, P. (2003). The appropriation of interactive technologies: Some lessons from placeless documents. *Computer Supported Cooperative Work*, 12(4), 465–490.
- Feenberg, A. (2010). *Between reason and experience: Essays in technology and modernity*. MIT Press.
- Fiore, S. M., & Wiltshire, T. J. (2016). Technology as teammate: Examining the role of external cognition in support of team cognitive processes. *Frontiers in psychology*, 7, 1531. <https://doi.org/10.3389/fpsyg.2016.01531>.
- Garro-Abarca, V., Palos-Sanchez, P. & Aguayo-Camacho, M. (2021). Virtual Teams in Times of Pandemic: Factors That Influence Performance. *Front. Psychol.*, 12, 624–637. <https://doi.org/10.3389/fpsyg.2021.624637>
- Grassini, S., & Laumann, K. (2020). Questionnaire measures and physiological correlates of presence: A systematic review. *Frontiers in Psychology*, 11, 349.
- Gravina, R., Parastoo, A., Ghasemzadeh, H., & Fortino, G. (2017). Multi-sensor fusion in body sensor networks: State-of-the-art and research challenges. *Information Fusion*, 35, 68–80.
- Gross, T. (2013). Supporting effortless coordination: 25 years of awareness research. *Computer Supported Cooperative Work (CSCW)*, 22 (4–6), 425–474.

- Grudin, J. (1994). Groupware and social dynamics: Eight challenges for developers. *Communications of the ACM*. 37(1), 92–105.
- Gutwin, C., & Greenberg, S. (1998). Design for individuals, design for groups: tradeoffs between power and workspace awareness, in *Proceedings of CSCW'98*, (pp. 207–216). Seattle, WA).
- Hannola, L., Richter, A., Richter, S., & Stocker, A. (2018). Empowering production workers with digitally facilitated knowledge processes—a conceptual framework. *International Journal of Production Research*. 56(14), 4729–4743.
- Hinds, P. J., & Mortensen, M. (2005). Understanding conflict in geographically distributed teams: The moderating effects of shared identity, shared context, and spontaneous communication. *Organization Science*. 16(3), 290–307.
- Hontvedt, M., & Øvergård, K. I. (2019). Simulations at Work—a Framework for Configuring Simulation Fidelity with Training Objectives. *Computer Supported Cooperative Work (CSCW)*, 1–29. <https://doi.org/10.1007/s10606-019-09367-8>
- Iacoboni, M., Molnar-Szakacs, I., Gallese, V., Buccino, G., Mazziotta, J. C., & Rizzolatti, G. (2005). Grasping the intentions of others with one's own mirror neuron system. *PLoS biology*. 3(3), e79.
- Ingusci, E., Signore, F., Giancaspro, M. L., Manuti, A., Molino, M., Russo, V., Zito, M. & Cortese, C. G. (2021). Workload, Techno Overload, and Behavioral Stress During COVID-19 Emergency: The Role of Job Crafting in Remote Workers. *Front. Psychol.* 12:655148. <https://doi.org/10.3389/fpsyg.2021.655148>
- Järvenpää, S. L., Shaw, T.R., & Staples, D. S. (2004). Toward Contextualized Theories of Trust: The Role of Trust in Global Virtual Teams. *Information Systems Research, INFORMS*. 15(3), 250–267, from <http://www.jstor.org/stable/23015796>. Accessed 25 July 2019.
- Kiesler, S., Siegel, J., & McGuire, T. W. (1984). Social psychological aspects of computer-mediated communication. *American psychologist*. 39(10), 1123.
- Koskinen, I., Zimmerman, J., Binder, T. Redstrom, J. & Wensveen, S. (2013). Design Research Through Practice: From the Lab, Field, and Showroom. *IEEE Transactions on Professional Communication*. 56(3), 262–263.
- Kruger, J., Epley, N., Parker, J., & Ng, Z.-W. (2005). Egocentrism over e-mail: Can we communicate as well as we think?. *Journal of personality and social psychology*. 89(6), 925.
- Kuo, F.-y., & Yu, C.-p. (2009). An exploratory study of trust dynamics in work-oriented virtual teams. *Journal of Computer-Mediated Communication*. 14(4), 823–854.
- Mackay, W. (2000). Responding to cognitive overload: Co-adaptation between users and technology. *Intellectica*. 30(1), 177–193.
- Latour B. (1999). On Recalling Ant. *The Sociological Review*. 47(1_suppl), 15–25. <https://doi.org/10.1111/j.1467-954X.1999.tb03480.x>
- Lee, K. M. (2004). Presence, explicated. *Commun. Theory*. 14, 27–50. doi: 10.1111/j.1468-2885.2004.tb00302.x
- Leslie, D., & Briggs, M. (2021). Explaining decisions made with AI: A workbook (Use case 1: AI-assisted recruitment tool). Available at SSRN 3808512. <https://ssrn.com/abstract=3808512> or <http://dx.doi.org/10.2139/ssrn.3808512>
- Lewicki, R. J., McAllister, D. J., & Bies, R. J. (1998). Trust and distrust: New relationships and realities. *Academy of Management Review*. 23(3), 438–458.
- Mattelmäki, T. (2006). Design probes. Aalto University. *Publication Series of the University of Art and Design Helsinki A*, 69/2006.
- McKnight, D. H., Choudhury, & V., Kacmar, C. (2002). Developing and validating trust measures for e-commerce: An integrative typology. *Information Systems Research*. 13(3), 334–359.
- Mueller, F., Maes, P., & Grudin, J. (2019). Human-Computer Integration (Dagstuhl Seminar 18322). *Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik*. <https://doi.org/10.4230/DagRep.8.8.18>

- Nardi, B. A., & Miller, J. R. (1991). Twinkling lights and nested loops: Distributed problem solving and spreadsheet development. *International Journal of Man-Machine Studies*. 34(2), 161–184.
- Noble, S. U., & Roberts, S. T. (2016). Through Google-colored glass (es): Design, emotion, class, and wearables as commodity and control. *Emotions, Technology, and Design (Academic Press.)* 187–212.
- Onwuegbuzie, A. J., & Johnson, R. B. (2006). The validity issue in mixed research. *Research in the Schools*. 13(1), 48–63.
- Paavola, S., & Miettinen, R. (2019). Dynamics of Design Collaboration: BIM Models as Intermediary Digital Objects. *Comput Supported Coop Work*. 28, 1–23. <https://doi.org/10.1007/s10606-018-9306-4>.
- Peake, J. M., Kerr, G., & Sullivan, J. P. (2018). A critical review of consumer wearables, mobile applications, and equipment for providing biofeedback, monitoring stress, and sleep in physically active populations. *Front. Physiol.* 28(9), 743. <https://doi.org/10.3389/fphys.2018.00743>.
- Pejoska, J., Bauters, M., Purma, J., & Leinonen, T. (2016). Social augmented reality: Enhancing context-dependent communication and informal learning at work. *British Journal of Educational Technology*. 47(3), 474–483
- Pirinen, A. (2016). The barriers and enablers of co-design for services. *International Journal of Design*, 10(3), 27–42.
- Preece, J. (2004). Etiquette, empathy and trust in communities of practice: Stepping-stones to social capital. *JUCS*. 10(3), 294–302.
- Pöysä-Tarhonen, J., Awwal, N., Häkkinen, P., & Otieno, S. (2020). From monitoring to sharing of attention in dyadic interaction : The affordances of gaze data to better understand social aspects of remote collaborative problem solving. In H.-J. So, M. M. Rodrigo, J. Mason, & A. Mitrovic (Eds.), *ICCE 2020 : Proceedings of the 28th International Conference on Computers in Education, Volume I* (pp. 109-118). Asia-Pacific Society for Computers in Education, from <https://apsce.net/upfile/icce2020/ICCE%202020%20Proceedings%20-%20Volume%20I%20v4.pdf>
- Quan-Haase, A., Cothrel, J., & Wellman, B. (2005). Instant Messaging for Collaboration: A Case Study of a High-Tech Firm. *Journal of Computer-Mediated Communication*. 10(4) JCMC10413. <https://doi.org/10.1111/j.1083-6101.2005.tb00276.x>
- Ramstead, M. JD., Veissière, S. PL. & Kirmayer, L. J. (2016). Cultural affordances: Scaffolding local worlds through shared intentionality and regimes of attention. *Frontiers in psychology*. 7, 1090.
- Rogers, P., & Lea, M. (2005). Social presence in distributed group environments: The role of social identity. *Behaviour & Information Technology*. 24(2), 151–158.
- Rousseau, D. M., Sitkin, S. B., Burt, R. S., & Camerer, C. (1998). Not so different after all: A cross-disciplinary view of trust. *Academy Management Review*. 23(3), 393–404.
- Salminen, M., Järvelä, S., Ruonala, A., Timonen, J., Mannerman, K., Ravaja, N., et al. (2018). Bio- adaptive social VR to evoke affective interdependence – DYNECOM. In *23rd international conference on intelligent user interfaces*, (pp. 73–77).
- Sanders, E. B-N. (2003). From user-centered to participatory design approaches, in *Design and the social sciences*, CRC Press. 18–25.
- Schmidt, K. & Bannon, L. J. (1992). Taking CSCW seriously: Supporting articulation work, *Computer Supported Cooperative Work (CSCW): An International Journal*. 1(1–2), 7–40.
- Schober, M. F., & Spiro, N. (2016). Listeners' and performers' shared understanding of jazz improvisations. *Frontiers in psychology*, 7, 1629.
- Sivunen, A., & Nordbäck, E. (2015). Social Presence as a Multi-Dimensional Group Construct in 3D Virtual Environments. *Journal of Computer-Mediated Communication*. 20(1), 19–36. doi:10.1111/jcc4.12090.
- Stahl, G. (2016). From intersubjectivity to group cognition. *Computer Supported Cooperative Work (CSCW)*. 25(4–5), 355–384. <https://doi.org/10.1007/s10606-016-9243-z>.
- Stewart, D. W., & Shamdasani, P. N. (2014). *Focus groups: Theory and practice*. 20. Sage publications.

- Teddlie, C., & Tashakkori, A. (2003). Major Issue and controversies in the use of mixed methods in the social and behavioural sciences. In C. Tashakkori & A. Teddlie (Eds.), *A Handbook of mixed methods in social and behavioural research*, (pp. 3–50.). Thousand Oaks, CA: Sage).
- Trenerry, B., Chng, S., Wang, Y., Suhaila, Z. S., Lim, S. S., Lu HY & Oh, P. H. (2021). Preparing Workplaces for Digital Transformation: An Integrative Review and Framework of Multi-Level Factors. *Front. Psychol.* 12, 620766. <https://doi.org/10.3389/fpsyg.2021.620766>
- Trigg, R. H., & Bødker, S. (1994). From implementation to design: Tailoring and the emergence of systematization in CSCW. In *Proceedings of the ACM Conference on Computer-Supported Cooperative Work, CSCW*. (pp. 45–54). Chapel Hill: ACM Press, '94.
- Törpel, B., Pipek, V., & Rittenbruch, M. (2003). Creating heterogeneity: Evolving use of groupware in a network of freelancers. *Computer Supported Cooperative Work*. 12(4), 381–409.
- Van der Pol, J. (2007). Facilitating online learning conversations. Exploring tool affordances in higher education. *Dissertation. IVLOS Series*, Utrecht.
- Wikström, V., Makkonen, T., & Saarikivi, K. (2017). SynKin: A Game for Intentionally Synchronizing Biosignals. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '17)*, (pp. 3005–3011). ACM, New York, NY, USA, <https://doi.org/10.1145/3027063.3053195>.
- Wikström, V., Falcon, M., Martikainen, S., Pejoska, J., Durall, E. Bauters, M., & Saarikivi, S. (2021). Heart Rate Sharing at the Workplace. *Multimodal Technologies and Interaction* 5(10), 60. <https://doi.org/10.3390/mti5100060>.
- Wulf, V., Müller, C., Pipek, V., Randall, D., Rohde, M., & Stevens, G. (2015). Practice-based computing: Empirically grounded conceptualizations derived from design case studies. In *Designing socially embedded technologies in the real-world*, (pp. 111–150.) Springer, London.
- Zaki, J., & Ochsner, K. N. (2012). The neuroscience of empathy: progress, pitfalls and promise. *Nature Neuroscience*. 15(5), 675.
- Zhao, X., Lampe, C., & Ellison, N. B. (2016). The social media ecology: User perceptions, strategies and challenges. In *Proceedings of the 2016 CHI conference on human factors in computing systems*, (pp. 89–100). ACM.
- Zhao, G., & Li, X. (2019). Automatic micro-expression analysis: open challenges. *Frontiers in psychology*, 10, 1833.

Authors' Note

This work has been supported by Business Finland, from Public research networked with companies funding services Grant number: 3350/31/2017.

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Human Technology

ISSN 1795-6889

<https://ht.csr-pub.eu>

Appendix 1 Scenarios

Group discussion using audio-conference

Scenario of use

HUMEX



Based on residents habits, we think that a bicycle sharing system...

How would this solution integrate with our existing systems?

Uhhm, it should work, I think



Are you interested in the project?

Yes, but I would like more information



I can send you the technical analysis

Ok.



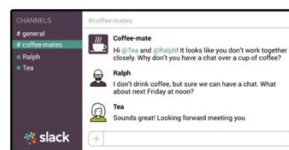
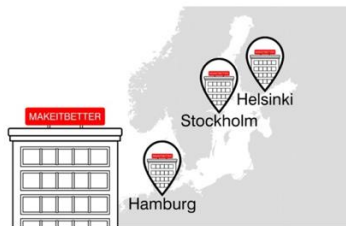
How do you relate to Jaakko's experience?

HUMEX

Community building using Instant Messaging

Scenario of use

HUMEX



How did the coffee-mate meeting go?

Well... I don't have time for this.



How do you relate to Tea's experience?

HUMEX

Facilitating a focus group using video-conferencing

Scenario of use

HUMEX



What was the last purchase you paid with your phone?



Mobile phone payment is very easy to track. You shouldn't use it

Timo, what makes mobile payment trustful for you?

Biometric authentication...



Bullshit! The system can be hacked anyways!

Thanks everyone for your time!



How do you relate to Selja's experience?

HUMEX

Appendix 2

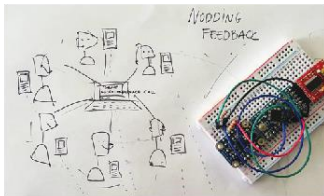
Card on prototypes

The Nodders

Are you there? Supporting presence in computer-mediated communication at work

Context

When comparing communication through digital technologies versus face-to-face interaction, digital communication is still perceived as more challenging. This creates some challenges for successful communication and collaboration in workplace settings. In particular, people's lack of feeling other interlocutors' presence during synchronous communications is an important challenge for successful collaboration, trust building and shared understanding.



Concept

The Nodders provides feedback about head gestures, like agreement, during audio calls and visualizes the information through animated emoticons. The prototype is meant to be used with a headset when taking part in a video conference.



Scenario of Use

Jaakko works as service designer at EasyLife. As part of his work, he uses audio calls to communicate with clients. He has difficulty to make sure his clients follow all the aspects discussed in the conversation. In order to improve communication, he uses The Nodders. The feedback provided by The Nodders helps him see if his clients agree with the ideas he explains them. This contributes to make the conversation smoother since he doesn't need to ask for confirmation continuously.



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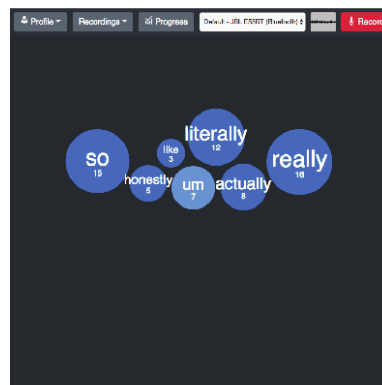
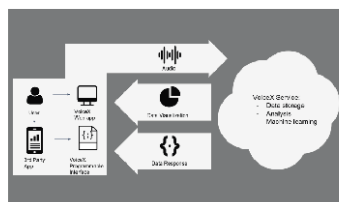
HUMEX A" Aalto University School of Arts, Design and Architecture

VoiceX

Improve your speechcraft.

Context

Time is often wasted when speaking, whether in meetings or presentations, because speakers aren't well prepared, don't know what to say, have to think a lot before finding the right words etc. This is frustrating to participants and may prove costly to companies. Our goal is to improve the performance of presenters and meeting attendees by enabling them to speak more fluently and efficiently.



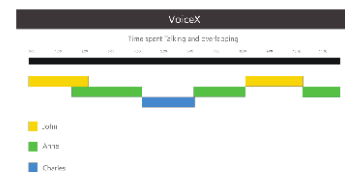
Concept

Our web application recognizes user-defined filling words from an uploaded or recorded audio file and provides statistics on how often the words were used. The statistics include comparisons to previous audio entries and shows the user's improvement over time.



Scenario of Use

A company has a lot of inefficient meetings. Participants don't prepare well enough and waste time talking about non-relevant things. Sometimes there are fights about turns and people tend to have problems communicating their points in a clear way. The company decides to start using VoiceX to improve the efficiency of their meetings and minimize the time wasted in them.



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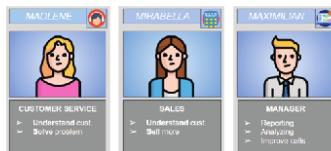
HUMEX A" Aalto University School of Arts, Design and Architecture

Mood

Recognizing emotions from live audio: An assistant to customer service and sales

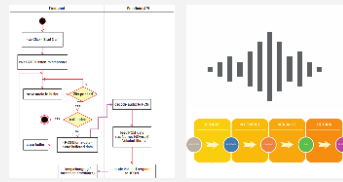
Context

Every company, B2C or B2B, does sales. The de-facto interface to this since the 20th century is a telephone. Most companies also have their customer support over a telephone. In both cases, employees of the company interact with customers, and misjudgments of emotions can end up costly. An employee may be inexperienced, unfocused, or succumbing to tunnel vision after tens of calls that day, which endangers either case.



Concept

We present a software tool, to assist an employee in sales or customer support. Our software taps in on customer's live audio, and relays recognized emotions to the employee, additionally giving recommendations for appropriate reactions.



Scenario of Use

Imaginary employee Madlene works in customer support of an insurance company, dealing with reclamations. Every day when accidents occur, the victims of said accidents, customers, face various emotions depending on their circumstances. A father whose child is in a hospital after a car accident they had, may be feeling distressed, expressing it as sadness or fear. If Madlene was to act overtly carefree (maybe after a joyful coffee break), the customer might think he is being neglected. (After all, his child is in a hospital, even though Madlene is not aware of this.) This may end in a retention, if she doesn't notice the sadness from his speech. Meanwhile a customer, whose car broke down mid-trip, could be frustrated of the situation to the point of anger. As opposed to the previous case of car accident, here a carefree calming attitude may be very welcome, reminding him how good it is he has an insurance!

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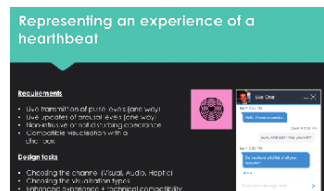
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Chat with Heart

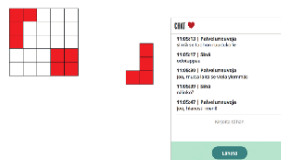
An instant messaging task for two players, simulating an expert advisor and client customer service situation, with a heart

Context

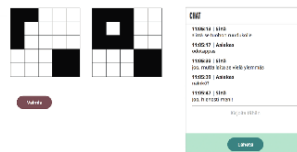
Customer service over online chat is often preferred to phone or email and increasingly used in many of Humex partner companies, sometimes together with chat bots. It is especially active in this area, and we wanted to investigate a controllable task to improve collaboration over instant messaging. The goal is to have a task with measurable outcomes, which can be used to support qualitative data in prototype development.



Customer



Chat service



Concept

In this prototype we are testing an abstract matrix reasoning task designed for the online chat environment, and experimenting with how to improve the chat experience by visualizing the advisors heart beat to the customer. Additionally, video data is collected to improve the heart beat prototype by moving towards camera based heart rate detection. The experiments are carried out by actual employees in a pop up lab at IF HQ, and real if customers who are participating from home.

Scenario of Use

Pekka's son Pikku-Pekka has dented Pekka's car, and he is unsure about whether his insurance will cover it. He is frustrated, and his first reaction is to vent out on the customer service employee Siiri who is trying their best to help him. Pekka starts off impolitely and bluntly demanding an easy resolution, but soon he realizes that he is causing Siiri to become agitated, since her heart is beating faster. This makes Pekka relate to Siiri more, and he changes to a more cooperative tone.



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DETERMINANTS OF THE ADOPTION OF AI WEARABLES - PRACTICAL IMPLICATIONS FOR MARKETING

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Abstract: *Wearables have become a natural element of human life, determining our way of perceiving, understanding and experiencing the world. Enriched with elements of artificial intelligence, they will change our habits and draw us into the digital dimension of the world - a space of uninterrupted interaction between people and technology. As a result, there are still new ideas for the effective use of AI wearables in the consumer space. The main aim of the article is to examine the determinants behind the acceptance of the AI wearables, with particular emphasis on the strength and nature of the relationship between the consumer and technology. The UTAUT2 model is used for this purpose. The article is a continuation of the previous reflections and analyses in this area; at the same time it constitutes an initial stage of research on the issues related to the adoption of AI wearables.*

Keywords: *wearable technology, artificial intelligence, consumer, augmented intelligence, marketing.*



INTRODUCTION

The issues related to human and AI-related technology are increasingly popular among researchers. Although the concept of artificial intelligence itself was already defined in the 1950s, the first publications on human and AI-related technology could only be found in 1983. In order to identify the current breadth of knowledge and the main directions of research in the field of human and AI-related technology, a systematic literature review was conducted. It covered three key areas: 1) determination of key databases and collection of publications, 2) selection and development of a complete publication database, and 3) bibliometric and content analysis.

In the first stage, the databases were selected using the availability of full text as a criterion. Thus, six studied international databases included Ebsco, Elsevier, Emerald, Web of Science, Scopus, Wiley, analysis of which allowed for the identification of over 4,000 publications on human and AI-related technology (full-text and peer-reviewed publications; human and AI-related technology in the title, abstract, keywords; repeated publications were removed). At this stage, it was decided not to limit the database to only social sciences but to also encompass publications in the field of engineering and technical sciences, medicine, humanities, as well as natural sciences. As part of the methodology of a systematic literature review, a number of publications from particular years were analysed.

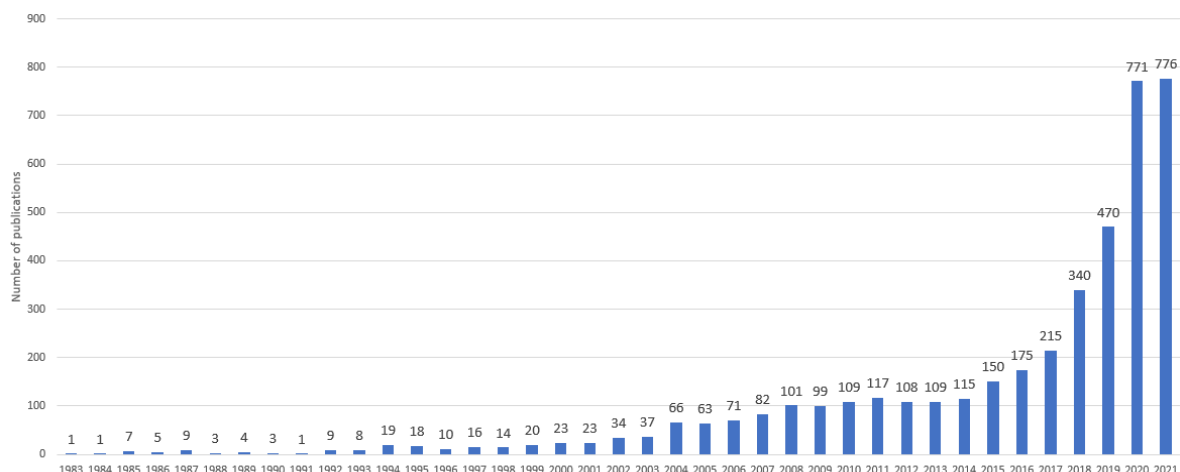


Figure 1. Analysis of the number of publications from particular years.

[Source: own study]

This allowed for the conclusion that the issues of human and AI-related technology are popular among researchers, and the rapid growth of interest has been observed since 2019. It seems fully justified due to the increasing possibilities of market implementation of solutions based on artificial intelligence, as well as their economic, legal and socio-cultural impact, which leads to the emergence of numerous scientific and research gaps. Taking into account, on the one hand, the indicated dynamics of the number of publications, and on the other hand, the intensity of the observed economic and socio-cultural changes caused by the implementation of AI in market practice, further analyzes were focused on the last 10 years.

The list of disciplines dealing with the issues of human and AI-related technology is very wide. Most publications in the analyzed area concerned Computer Science, Medicine, Engineering, Mathematics and Biochemistry, Genetics. However, the Field-Weighted Citation Impact analysis shows that it was the highest for publications in the field of Energy (2.86), Social Sciences (2.69), Business, Management and Accounting (2.68), Physics and Astronomy (2, 67), Arts and Humanities (2.28).

The obtained publication base was analyzed using bibliometric techniques. An analysis of keyword frequency and research problems was performed. Selected keywords related to the phrase of human and AI-related technology were subjected to quantitative analysis. At the same time, the visualization of attendance was presented in the form of a "word cloud", where the frequency of occurrence was reflected in the size and thickness of the font (Figure 2).

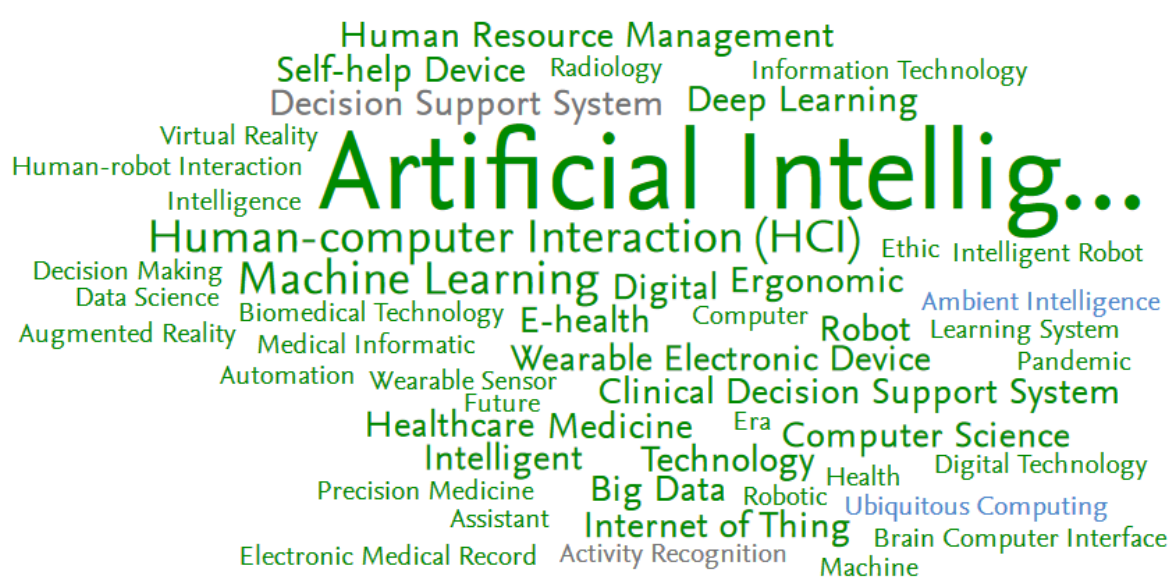


Figure 2. Keyword frequency analysis for: human and AI-related technology (2010 - 2021).

[Source: own study]

The most frequently appearing keywords are, obviously, artificial intelligence (increase in the number of publications in the analyzed period = +447.7%), Machine Learning (increase in the number of publications in the analyzed period = +3,450), Wearable Electronic Device (increase in the number of publications in the analyzed period = + 3.100%), Human-computer Interaction (increase in the number of publications in the analyzed period = +281.8%), Healthcare (increase in the number of publications in the analyzed period = +2.800%).

In spite of the fact that the issues of human and AI-related technology are capturing the interest of researchers practically all over the world, the analysis of the number of publications taking into account individual countries showed that the most active in this area are the United States, China, the United Kingdom, Germany and India (Figure 3).

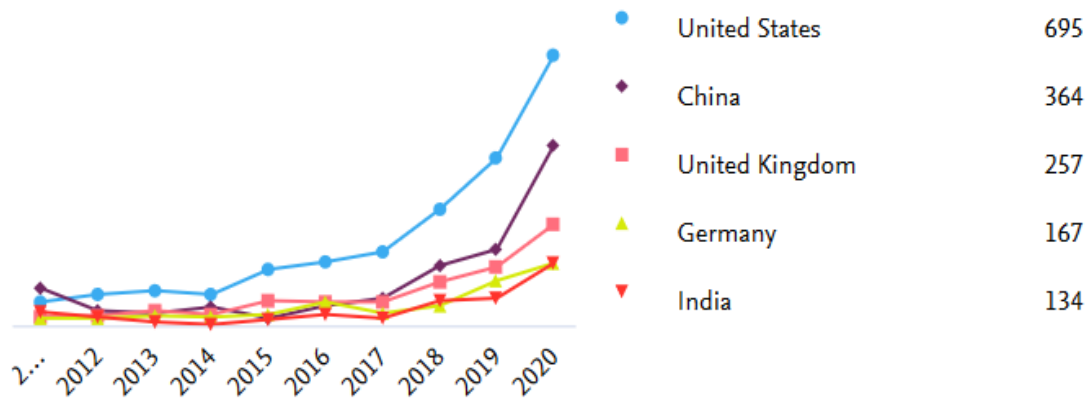


Figure 3. The most active countries in terms of the number of publications for the phrase: human and AI-related technology (2010 – 2021).

[Source: own study]

This does not seem surprising, given the current position and strategy of these countries in the field of the development of digital technologies, especially artificial intelligence and building their economic position in the world on this base.

American and European universities have the largest percentage contribution to the development of knowledge in the field of human and AI-related technology in this period, which may be related to the current level of economic development and the amount of expenditure they allocate to research on AI and its new potential applications, including also increasing the degree of commercialization of the findings (Figure 4).

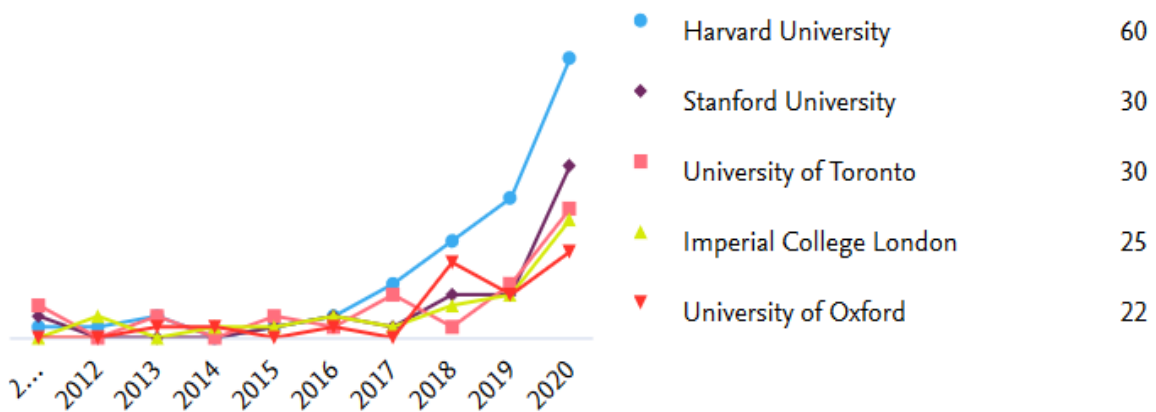


Figure 4. The most active scientific and research institutions according to the number of publications for the phrase: human and AI-related technology (2010 – 2021).

[Source: own study]

The highest level of citation rate of authors dealing with the issues of human and AI-related technology and their field-weighted citation impact was also analyzed. The authors that prevail here come from the United States of America and the United Kingdom (Table 1).

Table 1. The most frequently cited authors dealing with the issues of human and AI-related technology (2010 – 2021).

Author	Affiliation	Country/Region	Field-Weighted Citation Impact	Citation Count
Roggen, Daniel	University of Sussex	United Kingdom	30,70	1385
Lo, Benny	Imperial College London	United Kingdom	22,40	601
Cook, Dianie J.	Washington State University Pullman	United States	16,44	502
Acampora, Giovanni	National Institute for Nuclear Physics	Italy	16,27	439
Yang, Guangzhong	Imperial College London	United Kingdom	15,53	626
Kohane, Isaac S.	Harvard University	United States	11,02	437
Yu, Kun Hsing	Harvard University	United States	11,02	437
Aerts, Hugo J.W.L.	Maastricht University	Netherlands	12,5	372
Rahwan, lyad	Massachusetts Institute of Technology	United States	10,26	573
Floridi, Luciano	Queen Mary University of London	United Kingdom	10,08	296
Taddeo, Mariarosaria	Queen Mary University of London	United Kingdom	10,08	296

Subsequently, the conducted analysis was limited to the areas related to the category of Business, Management and Accounting, which is the area of interest of the authors, which allowed for the possibility to distinguish key research perspectives and indicate those areas of human and AI-related technology that require further exploration. The total number of publications in human and AI-related technology in the category: Business, Management and Accounting in the analyzed period was 74, and its Field-Weighted Citation Impact was 2.68. The analysis of the frequency of keywords related to human and AI-related technology in the category: Business, Management and Accounting and their quantitative analysis presented in the form of a "word cloud", where the frequency of occurrence was reflected in the size and thickness of the font (Figure 5), indicated that the key word in the group of the top five most popular keywords is artificial intelligence, where the increase in the number of publications in the analyzed period was +84.6%. The analysis of the remaining keywords showed the maintenance of a constant number of publications concerning the words: robot and ethics (no changes noted in this respect), as well as a significant decrease in the number of publications concerning: human resource management and philosophical aspect (in each case the indicator = -100%).

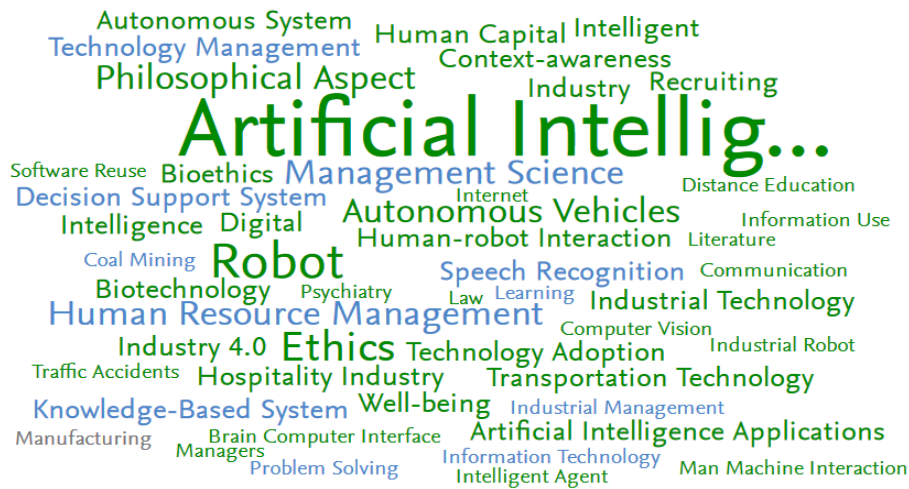


Figure 5. Keyword frequency analysis for human and AI-related technology for the category: Business, Management and Accounting (2010 – 2021).

[Source: own study]

The results of the analysis of the number of publications on human and AI-related technology in the category: Business, Management and Accounting, taking into account individual countries, showed that China, the United States and the United Kingdom are the most active in this respect. The research in this area is an important field of interest for the work of the University of Oxford, Queen Mary University of London, Henan Polytechnic University, University College London and the University of Birmingham. The analysis of the thematic areas of publications concerning the phrase: human and AI-related technology in the category: Business, Management and Accounting showed that the highest percentage was related to the Management of Technology and Innovation, slightly over 34% of publications. The smallest number of publications concerned Marketing 3.4% and Tourism, Leisure and Hospitality Management 2.3%.

At the same time, however, the analysis of the number of citations indicated that the highest value of the Field-Weighted Citation Impact indicator was achieved for publications in the field of Tourism, Leisure and Hospitality Management. Subsequently, it concerns Business and International Management, Management of Technology and Innovation and Marketing (Table 2).

Table 2. Field-Weighted Citation Impact indicator in individual thematic areas regarding the phrase: human and AI-related technology in the category: Business, Management and Accounting (2010 – 2021).

Subject area	Field-Weighted Citation Impact	Citation Count
Tourism, Leisure and Hospitality Management	18.92	163
Business and International Management	3.23	291
Management of Technology and Innovation	3.19	619
Marketing	2.92	53
Strategy and Management	1.96	111
General Business, Management and Accounting	1.87	69
Management Information Systems	1.40	107
Accounting	0.49	8

Then, an analysis of the citations of individual publications was conducted in order to assess their impact on further research (Table 3).

Table 3. The most frequently cited publications concerning the phrase: human and AI-related technology in the category: Business, Management and Accounting (2010 – 2021).

Title	Authors	Year	Source title	Cited by	Author Keywords
Applied artificial intelligence and trust-The case of autonomous vehicles and medical assistance devices	Hengstler M., Enkel E., Duelli S.	2016	Technological Forecasting and Social Change vol. 105	195	Artificial intelligence; Automation; Autonomous driving; Autonomous vehicle; Medical assistance; Trust
From high-touch to high-tech: COVID-19 drives robotics adoption	Zeng Z., Chen P.-J., Lew A.A.	2020	Tourism Geographies Vol.22 no. 3	143	Artificial Intelligence; COVID-19 pandemic; drones; high-tech; high-touch; human-robot interaction; Robotics
Artificial Intelligence and the 'Good Society': the US, EU, and UK approach	Cath C., Wachter S., Mittelstadt B., Taddeo M., Floridi L.	2018	Science and Engineering Ethics vol.24, no.2	134	Algorithms; Artificial intelligence; Data ethics; Good society; Human dignity
Ethical Design of Intelligent Assistive Technologies for Dementia: A Descriptive Review	Ienca M., Wangmo T., Jotterand F., Kressig R.W., Elger B.	2018	Science and Engineering Ethics vol. 24, no. 4	57	Artificial intelligence; Assistive technology; Dementia; Ethical design; Neurotechnology; Proactive ethics; User-centered
The Ugly Truth About Ourselves and Our Robot Creations: The Problem of Bias and Social Inequity	Howard A., Borenstein J.	2018	Science and Engineering Ethics vol. 24, no. 5	55	Artificial intelligence; Design ethics; Implicit bias; Professional ethics; Robot ethics

Among the five most cited publications in the analyzed period for the phrase of human and AI-related technology in the category: Business, Management and Accounting, the issues of trust and ethics were mainly addressed, which is reflected in intensive efforts to build a uniform legal framework for the implementation of solutions based on AI within the EU, UNESCO or OECD.

The analysis of the collected material clearly indicates the topicality of research on issues related to human and AI-related technology, including the following categories: Business, Management and Accounting. This subject has been intensively undertaken by researchers representing various scientific disciplines, especially in the last 2-3 years. The multiplicity and differentiation of the topics related to human and AI-related technology, on the one hand, result in a desire for a holistic approach to the issues discussed, on the other, due to their complexity and multithreading, an increasing need to place them in a narrowly defined context emerges.

The conducted analysis showed that wearables are one of the most frequently appearing keywords related to the issues of human and AI-related technology research. At the same time research on the level of their social acceptance is still little known, and in the context of enriching wearables with completely new functionalities resulting from the implementation of AI which justifies the need for research in this area.

The main goal of the article is to identify factors influencing the acceptance process of AI wearables, with particular emphasis on the current research issues in human and AI related technology. In this regard, the UTAUT2 model (Venkatesh et al., 2012) was used, which is an extended unified theory of technology acceptance and use, with strong empirical justification. This article presents the experiences of consumers resulting from their previous interactions with wearables, including the assessment of the possibility of enrichment with AI-based solutions, which is part of the discourse on human and AI-related technology and contributes to expanding the current knowledge on this subject.

In order to achieve the research objectives, the following structure of the work was adopted: a review of the literature on the theoretical foundations of wearables and their possibilities, with particular emphasis on the consumer dimension, the UTAUT 2 model, hypotheses, methodology of the research, presentation of the results of the structural model, and finally, a discussion and identification of the theoretical and practical implications. Limitations to the conducted research were also taken into account.

Wearable Technology in Consumers' Life

Wearable technology refers to all kinds of advanced electronic devices or computers that are integrated with clothing and accessories used by people or their bodies, and that provides personalized functionalities (Oinas-Kukkonen, 2013; Wright & Keith, 2014; Choi and Kim, 2016; Vaitkevičius et al., 2019). These include electronic devices, software, data transmitters, and sensors that are part of clothing, jewelry, and body-worn accessories (Liu et al., 2016; Wright & Keith, 2014). Wearable devices are able to provide measurement and analysis of physiological and psychological data (Spagnolli et al., 2014), communication, two-way data exchange between a person and their environment (Kalantari, 2017, Fang & Chang, 2016), using applications installed in wearables or other related to mobile external devices (Muaremi et al., 2013). The wearable technology is based on wireless communication with the Internet or other devices, allowing access to information, including in real time (Park et al., 2014; Liu & Guo, 2017). Using various types of sensors, information is collected about consumers, analyzed, and then stored in appropriate applications. Wearables cover a wide range of devices, such as the currently popular smartwatches, smart bands, headphones, as well as glasses, including sunglasses, smart clothing and jewelry (non-invasive solutions) (Chuah et al., 2016; Chen et al., 2016). There are also increasingly innovative and futuristic solutions, such as: electronic skin patches as well as smart chest straps, contact lenses, electronic skin products or smart patches. There is also talk of the possibility of direct implementation of wearables into the human body, e.g. in the form of chips (invasive solutions). Wearables can be classified based on their form and purpose (to be worn on the head, e.g. a helmet, body e.g. clothing, hand e.g. smartwatch, jewelry) or their functions (e.g. monitoring a healthy lifestyle, information support etc.) (Mewara et al. 2016). A more complex taxonomy of wearables includes a number of features of these types of devices: the scope of functionality (monofunctional versus multifunctional), the level of invasiveness (invasive versus non-invasive), character (active versus passive), communication mode, area (sector, industry) applications and possibilities of their use (disposable versus reusable) (Park et al., 2014).

Wearables have an increasingly wider range of applications, hence solutions based on wearable technology can be found, for example, in medicine, care for seniors and young

children, the army, sport, trade, marketing, video games or at workplaces. The attributes of wearables determine the level of their usefulness in individual market sectors. According to Mewara, these attributes are both physical (lightweight, aesthetically pleasing, invisible, shape conformable) and functional (multi-functional, configurable, responsive and a bandwidth to enable the degree of interactivity) (Mewara et al. 2016).

It is estimated that global consumer spending on wearables will exceed \$ 90 billion in 2022 (<https://www.statista.com/topics/1556/wearable-technology>) although this market is still very far from its saturation level. The analysis of trends on the wearables market allows for the assumption that its dynamics will be significantly accelerated by the parallel development of technologies such as artificial intelligence and 5G, which will increase the wearables' computing power and enable more accurate measurements, improving the reliability of the results provided. The possibility of increasing miniaturization of wearables is also important. Gartner predicts that by 2024 the possibilities of miniaturization will increase to such an extent that 10% of all such devices will be invisible to the user (Rimol, 2021). Undoubtedly, wearables will evolve in terms of their form (size, offered functionalities, intuitiveness, durability, design), which are becoming more desirable in order to satisfy consumer needs and to increase interaction with the devices. This has an impact on deepening existing behavioral experiences and constantly creating new forms of behavior (Oh & Kang, 2021; Lunney et al., 2016).

The wearables market is not homogeneous, both in terms of the manufacturers (e.g. Apple, Xiaomi, Huawei, Samsung) (<https://www.idc.com/promo/wearablevendor>) and the available products that have different levels of technological advancement and the possibilities that are on offer to the consumers. This entails a number of security challenges (in particular, data collection, management, processing and possible sharing, but also product defect and liability) and privacy (Gao et al., 2015). Moreover, regulations in this regard may differ from country to country or region to country around the world (Garattini et. Al, 2019). The issue of ethical considerations is also important (potential risk of manipulation, limiting choices, crossing the border of technology interference in customers' lives and their perception in society). It is more than just a product that meets a specific need. "It is a manifesto that allows you to define yourself and others in a given group through the symbolic meaning of a given device" (Hajo & Galinsky, 2012; Oh & Kang, 2021). In such an approach, wearables become a symbol of the customers' identity, reflecting their attitude towards the world and people. This may result in the lack of trust in a given solution or even discomfort resulting from its use and lead to technophobia in relation to a given device or technology or the effects resulting from its use. However, research shows that the role of trust varies depending on the context. It increases in a situation perceived by the consumer as crucial, e.g. health (Dierks, 2007), and is of little importance in normal or safe contexts (Esmaili et al., 2011).

Augmented Intelligence of the Customer

Wearables combine physical space (real world) and cyberspace through maximum use of technology, leading to building hyper-intelligence based on the multiplication of the effects of its synergy with humans. Undoubtedly, the development of new technologies, especially AI, is now perceived as a natural sequence of further consumer evolution. It is a vision of integrating new technologies and solutions based on them from various fields for the benefit of mankind (Holroyd, 2020). Artificial intelligence combines elements of computer science, cognitive

science and logic. It is aimed at recreating and improving human behavior. Among other things, algorithms can identify specific functions and patterns of behavior, and then learn them, stimulate them and improve their own actions. (Ertel, 2017). It has the ability to support customers - it plays an auxiliary role, strengthens human intelligence, not replace it (Crigger & Khoury, 2019; Hebbar, 2017), which leads to a gradual blurring of the boundary between artificial and human intelligence, creating a space for the so-called Augmented Intelligence of a human. Technology determines the way of perceiving the world, experiencing and feeling, while providing many interactive tools to deepen and broaden these experiences.

Artificial intelligence (AI), understood as models of human behavior and solutions allowing for the simulation of these behaviors, can be perceived in cognitive categories (I deepen my knowledge, I know more) or in human behavioral categories (efficiency of implemented activities versus perfect reproduction of human behavior, adaptability) (Russell & Norvig, 2016). Therefore, it refers to the effective analysis of huge databases, processing data into knowledge that is then used to generate behaviors based on it, which makes AI able to mimic a human (Jarrahi, 2018). This leads to wearables becoming more effective (Hoffman & Novaka, 2015). AI wearables, acting proactively, create a space for real-time integration of the obtained data. The devices are able to detect consumer activity while providing specific, necessary information at a given moment without the need to perform additional activities (e.g. logging into the system). They record everything happens around them and at the same time outside them, providing a new digital environment. The resulting data stream allows the discovery of a number of consumer behavior patterns. This translates into a change in these behaviors or leads to the remodeling of the cause and effect processes that determine the different behaviors, e.g. through a system of digital prompts that the consumer receives on an ongoing basis (steps taken, stress level, number of calories burned, missed calls, etc.) in accordance with their daily life cycle, which improves the individual management style (Shin et.al., 2019). This changes the performance of people's daily activities and affects the way people live, travel, learn, work and spend free time (Chen, 2012), although skeptics have doubts as to whether this change is long-term. Thanks to technological support, a customer knows more, understands the occurring cause-effect relationships much better, is able to predict more accurately, and the processes are conducted much faster and more efficiently. This leads to an increase in their cognitive abilities (Lisboa, 2018; Sharma, 2019). "We stimulate and release the possibilities of the human mind that have not been available to us so far" (Corrigan, 2012; Pasquinelli, 2015; Von Ahn, 2013).

Therefore, Augmented Intelligence aims to support and strengthen customer intelligence as an effect of its synergy with AI, in which there is mutual complementation and coexistence (complementarity) in a manner beneficial to both parties (Rold, 2019). "Humans and machines can go hand in hand" (Kotler et al., 2021). This continuous process makes the technology's ability to provide new benefits unlimited, and it constantly develops while stimulating customer development. So, digital transformation affects technology as much as people (Kane, 2019). Man and technology are then an inseparable whole (Mann, 2014). The resulting customer - technology interface enables interaction and cooperation in a specific context, while affecting the level of efficiency of the tasks (Xiong et al., 2021). This allows for things to be done that were not possible before. As a result, AI wearables can become more attractive to the customer, making it easier and more effective (Hoffman and Novak, 2015). They are becoming increasingly useful in everyday activities. Despite the enormous potential and added value

created by the synergy of AI and wearables, an opinion exists that this is only a form of luxury that will be of little use in the future.

Experts believe that the size of the global AI wearables market will reach USD 38.3 billion by 2025, which results, on the one hand, from a wide range of benefits they offer, and on the other hand, from the dynamics of AI development. At the same time, concerns are raised by the fact that, as Gartner experts identify, by 2023 the behavior of approximately 40% of the world's population will be digitally “tracked”, and the information derived will become the basis for predicting and proactively creating social behavior. This intensifies the debate on privacy, security and ethics in the tech world, taking into account the fundamental rights of the consumer, especially when the status of previous technologies is undermined by successive digital innovations (Jouhki, 2020). The evolutionism of such an approach sets the directions for the development and adaptation of a human being and a consumer, assuming that under the influence of technology, and as a result of interaction with it, it changes over time, also changing its environment at the same time. As a result, the rapid development of Augmented Intelligence resulting from the implementation of AI wearables is possible only on the condition of understanding its essence and increasing social acceptance in this area (Xia and Maes, 2013).

Social Acceptance of AI Wearables

Acceptance of technologies and based solutions is a manifestation of the consumer's attitude. It is important both for the declared and implemented behaviors and influences their further development as an individual (Venkatesh & Davis, 2000). These behaviors are the result of the cognitive process and may lead to the acceptance, use or negation and rejection of individual solutions (Venkatesh & Brown, 2005). Acceptance of technology is therefore the effect of positive and/or negative emotions related to the perceived, individually, level of simplicity of using a given solution and the needs that can be satisfied in this way (Wang et al., 2011). In this respect, the importance of the context in which wearables are implemented by consumers (activities they support) increases significantly, and decisions in this regard are preceded by an assessment of the features that these devices have and their price availability (Sachini et al., 2021). The profile of consumers is not without significance (the characteristics of a given group, including their lifestyle, their level of technological advancement or the nature of their needs) (Yang et al., 2016), because wearables must naturally fit into their everyday lives. This requires understanding the habits, attitudes and preferences of customers, including their acceptance of technology and involvement in the process of interacting with it. The characteristics that determine the propensity of customers to use wearables relate to specific categories of factors that translate into the level of satisfaction of using the device. This applies to physical features, including visual features of a given device (e.g. its size, colors, design, aesthetics, weight), functional features (ease of taking off and putting on, intuitive operation, multifunctionality, mobility, susceptibility to destruction), behavioral (range of possible interactions, including interpersonal, the level of generated experiences, evoked emotions), symbolic (brand, symbol of a given way of life, expression of the customer's identity), related to safety (does not lead to allergies, does not pose a threat to health in any way, provides protection against cyber-attacks) (Eservel et al., 2021; Chau et al., 2019; Nascimento et al., 2018). The context of the wearable's adoption is also important (Canhoto, Arp, 2017). They

accord with a complex space of moral and ethical rules, ways of communication, habits and their symbolism, fashion and aesthetics (Norene, 2016), which leads to an increased involvement in this type of interaction.

There are currently numerous models available that try to explain the issues of social acceptance of technology, such as: Theory of Reasoned Action (TRA), The Technology Acceptance Model (TAM Social Cognitive Theory (SCT), Theory of Planned Behavior (TPB) or The Unified Theory of Acceptance and Use of Technology (UTAUT and UTAUT2). The analysis of the research conducted in this area shows that the TAM model is very popular, which may, however, insufficiently explain consumer behavior (Lin et al., 2007) and lead to simplifications. The process of the adoption of AI wearables, in this study, the UTAUT2 model was adopted due to its wide range of advantages. It is the model that is considered to have a higher explanatory power compared to other models of technology acceptance. It is comprehensive and based on a diversified scope variables and constructs. It allows both to effectively explain customer behavior while interacting with technology and to predict it (Gu et al., 2016; Venkatesh et al., 2012), which is important from the point of view of artificial intelligence solutions discussed in the study.

METHODS

Study Context

A literature review based on the full-text databases of Ebsco, Elsevier, Emerald, Web of Science, Scopus, Wiley shows an intense increase in the level of interest in the issue of wearables, starting from 2014, with the highest increase in publications recorded between 2014-2019. The analysis identified 50,476 publications on the subject of wearables (reviewed full-text publications; the phrase wearable is in the title, abstract, key words) in 2010 – 2021, of which publications in the Business, Management and Accounting category, which is the subject of the authors' further analysis, accounted for 443 publications. The largest number of studies in this area is conducted in the United States, India and China.

The analysis of the frequency of keywords related to wearables in the Business, Management and Accounting category and their quantitative analysis presented in the form of a "word cloud", where the frequency of occurrence was reflected in the size and thickness of the font (Figure 6), indicated that the key words are: wearable sensors (increase in the number of publications in the analyzed period = +433.3%), and wearable computer (increase in the number of publications in the analyzed period = +150.0%).



Figure 6. Keyword frequency analysis for wearables for the category: Business, Management and Accounting (2010 – 2021).
[Source: own study]

The analysis of the thematic areas of publications concerning the analyzed phrase in the Business, Management and Accounting category showed their dominant importance for Management of Technology and Innovation as well as Strategy and Management. At the same time, the analysis of the number of citations showed that the highest values of the Field-Weighted Citation Impact indicator are achieved for publications in the field of Industrial Relations (3.49), Tourism, Leisure and Hospitality Management (3.22) and Marketing (2.27). The review and assessment of issues raised in the most cited publications on wearable devices in the analyzed category indicates a dominant role of the issue of acceptance of wearable technologies in various market sectors:

- Gao Y., Li H., Luo Y., (2015). An empirical study of wearable technology acceptance in healthcare. *Industrial Management and Data Systems*, 115(9) - (cited by 259)
- Rauschnabel P.A., Ro Y.K., (2016). Augmented reality smart glasses: An investigation of technology acceptance drivers. *International Journal of Technology Marketing*, 11(2) - (cited by 140)
- Shin D.-H., (2017). Conceptualizing and measuring quality of experience of the internet of things: Exploring how quality is perceived by users. *Information and Management*, 54(8) - (cited by 106)
- Tussyadiah I.P., Jung T.H., tom Dieck M.C., (2018). Embodiment of Wearable Augmented Reality Technology in Tourism Experiences. *Journal of Travel Research*, 57(4) - (cited by 98)
- Canhoto A.I., Arp S., (2017). Exploring the factors that support adoption and sustained use of health and fitness wearables. *Journal of Marketing Management*, 33(1-2) - (cited by 86)

It seems that despite the popularization of wearables and the related research on various contexts of their use (medicine, automotive, tourism, etc.), understanding of the broad spectrum of the process of their social acceptance is still limited. Comprehension of the impact of factors, such as the degree of innovation of wearables, their usefulness, as well as price value, availability, social influence and the acceptance or rejection in the group of end users is of key importance for marketing departments. Identification of the general social attitude towards wearables and the assessment of factors that may intensify or weaken this process requires further explication both at the level of the general framework of this acceptance, and at the detailed level, determined by the specificity of a given market sector. This knowledge is even more important in the case of solutions that are currently in the early stages of development, such as AI wearables, and which, according to analysts, may develop dynamically and undergo intensive commercialization in the coming years. This is important both for the stage of their further conceptualization, innovation, prototyping and the context of their future use, adaptation to the preferences and real needs of consumers with different levels of digital skills and technology-related experience. The conducted research helps to understand the essence of this process, which may be of importance for the further sustainable development of technologies to support people and constitute an element of their augmented intelligence. This justifies the decision made by the authors to conduct the preliminary research on AI wearable technology acceptance as a new area of human and AI related technology, in particular taking into account their marketing dimension.

Data Collection Instrument

The UTAUT2 model used by the authors was applied concerning, for example, mobile games, smartphone apps, internet banking, and e-learning systems. The analyzes conducted are based on the replication of original research (nuance of the studied dependencies, e.g. with regard to subsequent solutions based on digital technologies or their applications, taking into account different sectors or countries) or introduce variables to expand the scope of the research, in particular in the case of solutions commonly available on the market, e.g. various types of applications. The conducted research was preliminary, therefore, it was limited to replication research, considering that the obtained results will provide clues as to the variables with which the model should be enriched, as well as contribute to the implementation of experimental research based on real human and AI related technologies in AI wearables. The model used by the authors was adopted in accordance with the principles of cultural adaptation of measurement scales, ranking at the level of translation with the admission of modification where a literal translation was not possible and it was adapted to the specific context of the study

The study used a quantitative research approach (online survey), based on a structured research questionnaire. It consisted of 22 questions, divided into three parts. The first part includes questions about the respondents' characteristics, the second part includes questions that allow to measure the construct, and the third part includes questions about the respondents' opinions about the possibilities and challenges resulting from the potential implementation of AI in wearables. Questions relating directly to the UTAUT2 model construct included a total of 28 items, each of which was measured using a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). It took about 20 minutes to complete the survey questionnaire.

A pilot study was conducted on a group of 20 respondents, which made it possible to eliminate potential ambiguities in the wording and repetitions. It was also confirmed that all items of the questionnaire had an appropriate level of confidence in internal consistency. After this validation process, the questionnaire was used in the proper research.

Due to the fact that the authors were aware of how the concept of artificial intelligence is perceived among people who are not related to technology, and shape their knowledge based on science fiction publications, games and information taken from the Internet, it was explained in detail before starting the research. The respondents were given the aim of the study, the essence of AI and its practical examples in the devices they use on a daily basis.

Development of Hypotheses

The emergence of artificial intelligence gradually, often unknowingly, changes the customer's life and surroundings. Subsequent products enriched with the possibilities resulting from this technology allow a consumer to go beyond the current cognitive and behavioral spheres. At the same time, however, the dissemination of this technology raises many concerns, which may hinder and slow down the acceptance process of AI wearables. For the purposes of preliminary research on determinants of the adoption of AI wearables, an assumption was made to transfer the hypotheses previously stated and confirmed in the literature in order to identify their effectiveness in the research on the newly developing AI wearables market. This will help define the general framework for social acceptance for these devices, with particular emphasis on the marketing perspective for their further commercialization. It was also assumed that the resulting empirical material would be used to modify and enrich the existing construct variables in further research on this issue.

Performance expectancy

Performance expectancy is defined as the degree to which consumers believe that using a given technology will help them achieve greater efficiency (benefit) in performing certain activities (Venkatesh et al., 2003). From this perspective, AI wearables can support consumers in monitoring their daily activities, analyzing their basic life parameters and decision-making processes. When consumers are convinced that these types of devices are useful in their lives, the greater the likelihood the devices will be accepted (Alalwan et al., 2017), which allows for the hypothesis that:

H1. Performance expectancy positively affects the behavioral intentions to adopt AI wearables

Effort expectancy

Effort expectancy is defined as the degree of ease associated with the process of using a given technology (Venkatesh et al., 2003). The majority of available studies (Dhiman et al.) in this regard indicate that the more consumers are convinced that the use of such devices is simple and intuitive, the more likely they are to use them. This means that effort expectancy may have a positive impact on consumer intention to use AI wearables, which leads to the following hypothesis:

H2. Effort expectancy positively affects the behavioral intentions to adopt AI wearables.

Social Influence

Social Influence is defined as the degree to which the consumer is convinced that people important in their life, such as family, friends, etc. (the social circle of an individual), believe that they should use a given technology and based solutions (Venkatesh et al., 2003). Social influence is particularly important in the initial period of acceptance of such solutions, where the reference group may, through sharing information, opinions and own experiences, determine the interest and willingness to use the devices (Alalwan et al., 2017), which allows for a hypothesis that:

H3. Social Influence positively affects the behavioral intentions to adopt AI wearables.

Facilitating conditions

Facilitating conditions are defined as the degree to which the consumer is convinced that the existing infrastructure, e.g. technological one, supports a given technology and devices based on it (Venkatesh et al., 2003). Their evaluation may either facilitate the approval process or slow it down and hinder it. Available studies show that consumers will be more likely to use a given technology if it is believed that there is support for its existence and further development (Alalwan et al., 2017). Therefore, it was hypothesized that:

H4. Facilitating conditions positively affects the behavioral intentions to adopt AI wearables.

Hedonic Motivation

Hedonic motivation is associated with enjoying the use of a given technology (Venkatesh et al., 2012). It seems natural that consumers will be more likely to reach for solutions that are found to be amusing, enjoyable to use or arouse joy and curiosity (Alalwan et al., 2017). AI wearables attributes can therefore become a manifestation of consumers' identity, which will positively affect the intention and decisions about their use. This allows the hypothesis that:

H5. Hedonic Motivation positively affects the behavioral intentions to adopt AI wearables

Price Value

Behavior in which potential users of a given technology compare, before making a purchase, the benefits they will obtain with the costs incurred for its purchase, seems justified. Price value becomes a compromise for the consumer between the expected benefits and the necessary costs. "The greater the price value, the higher would be the motivation to adopt the new technology" (Dhiman et al.2020) Therefore, the following hypothesis was put forward:

H6. Price Value positively affects the behavioral intentions to adopt AI wearables.

Habit

Habit is most often defined as the extent to which customers tend to perform behaviors automatically because of learning (Vankatesh et al., 2012), which leads to repeatability of their behavior, and is the result of their previous experiences. The past therefore determines the current decisions of customers and their behavior.

H7. Habit positively affects the behavioral intentions to adopt AI wearables

Sample

The study was based on a nationwide research conducted on a representative sample of 1,054 Internet users aged 18 and over in the period July-August 2021. 52.1% of the study participants were women, and 47.9% were men. The smallest number of respondents were under 25 (6.5%). The respondents aged 25-34 constituted 13.7% of the respondents, and those aged 35-44: 17.8%. Every fourth respondent was aged 45-54, and people aged 55-64 accounted for 16.9% of the respondents. The respondents over 65 years old constituted 19.1% of the respondents. Slightly more than 36% of the respondents had higher education, and 35.5% were people with secondary education. The respondents with primary and basic education accounted for 28.3% of the respondents. 38.1% of the respondents lived in small towns (villages and towns with less than 5,000 inhabitants), 14.7% of the respondents lived in cities with 5,001-30,000 inhabitants, and respectively: cities with 30,001-50,000 inhabitants (13.0%) and over 50,000 inhabitants (34.2%), of which every tenth respondent lived in the largest cities (over 500,000 inhabitants). The respondents assessed their financial situation most often as average, which was indicated by 59.7% of the respondents. Every fourth respondent assessed it as good, and 2% of respondents considered it very good. 11.3% saw it as bad, and 2.7% too bad. Almost 21% of the respondents were convinced of their high level of technological advancement, resulting from experience. 41.4% considered themselves to be moderately technologically advanced, but as many as 38% believed that they had little experience in this field, which, in their opinion, translates into a low level of technological advancement.

RESULTS

The Main Descriptive Analysis

Slightly over 11% of respondents encountered the concept of wearables for the first time three years ago, every fifth respondent had a chance to deal with it in the period of 1-3 years, and almost 41% had this contact in less than the last year. At the same time, however, 27.5% of respondents had never come across it before. 30% of respondents declared having and using this type of device, mainly smartwatches and fitness trackers. As expected, the age of the respondents happened to be a statistically significant variable. The willingness to buy this type of devices was the highest among respondents aged 25-34 (45% of respondents in this age group), and then it decreased with age. The existence of statistical relationships was also observed in the case of the level of technological advancement of the respondents, resulting from their experience. The higher it was in the opinion of the respondents, the more likely they were to purchase this type of equipment.

Respondents who had wearables were definitely satisfied with the devices, as indicated by almost 89% of respondents. Their experiences so far have been assessed positively, and the derived satisfaction can prove important in the case of making a decision concerning a purchase of a new version enriched with AI elements. The respondents appreciated, above all, the

functionality of their devices, their usefulness in everyday life, as well as the aesthetics and design. They considered the possibility of enriching wearables with solutions based on artificial intelligence as a natural market response to the needs of consumers. At the same time, the respondents indicated several areas of development of the existing functionalities of their wearables, in which, in their opinion, artificial intelligence could be of key importance: measuring daily activities (e.g. distance traveled) (77%), health diagnostics (74%), controlling smart home systems (72%), handling of phone calls and incoming notifications (71%). At the same time, among the biggest challenges related to AI wearables, respondents emphasized a significant increase in the risk of cyber threats aimed at obtaining data about individual users (64% of respondents), limiting their privacy (61%) and the potential unethical use of data collected by AI wearables (57%).

Measurement And Structural Model

The scales used were analyzed for reliability and validity via CFA.

Table 4. Fit indices of the measurement and structural models.

Fit Index	Measurement model	Structural model
RMR	0.065	0.066
CFI	0.933	0.931
GFI	0.832	0.830
NFI	0.891	0.890
IFI	0.933	0.932
TLI	0.921	0.920
PGFI	0.660	0.661
AGFI	0.788	0.787
RMSEA	0.067	0.067

The analysis showed that the value of the AGFI and NFI coefficients for the model are slightly below the threshold values.

Table 5. The Measurement Model.

Construct	Item	Loadings	CR	AVE
Expected performance	PE1	0.799	0.91353	0.725641
	PE2	0.877		
	PE3	0.877		
	PE4	0.852		
Effort expectancy	EE1	0.884	0.91576	0.731172
	EE2	0.822		
	EE3	0.87		
	EE4	0.843		
Social Influence	SI1	0.92	0.928117	0.811518
	SI2	0.877		
	SI3	0.905		
	FC1	0.447		
Facilitating conditions	FC2	0.651	0.793736	0.503319
	FC3	0.844		
	FC4	0.823		
	HM1	0.536		
Hedonic Motivation	HM2	0.9	0.812634	0.601526

Price Value	HM3	0.841		
	PV1	0.789	0.865652	0.68259
	PV2	0.861		
	PV3	0.827		
Habit	HT1	0.799	0.816978	0.53191
	HT2	0.614		
	HT3	0.639		
	HT4	0.839		
Behavioral Intention	BI1	0.828	0.902796	0.756075
	BI2	0.879		
	BI3	0.9		

Notes: PE-Expected performance, EE-Effort expectancy, SI-Social Influence, FC-Facilitating conditions, HM-Hedonic Motivation, PV- Price Value, HT-Habit, BI-Behavioral Intention, CR-composite reliability, AVE-average variance extracted

Source: own study

The reliability of the measurement was determined using the composite reliability CR (Fornell, Larcker, 1981). The acceptable minimum is 0.7, and the upper limit is 0.95 (Hair et al., 2013). Relevance was assessed in terms of convergent validity and discriminant validity. Convergent validity is usually assessed using average variance extracted AVE, the value of which for each latent variable in the model should exceed 0.5 (Fornell, Larcker, 1981).

Discriminant validity (Fornell, Larcker, 1981) for individual constructs of the research model and their mutual correlations are presented in the table below (all correlations are significant at the level of $p < 0.001$). The square roots of AVE were compared with the appropriate correlation coefficients, and their higher values indicate a positive discriminant validity test, therefore the individual latent variables differ significantly from each other. The reliability and validity of the measurements used for the proposed factor structure made it possible to create a multidimensional construct measuring the analyzed ratio against AI wearables.

Table 6. The Correlation Matrix and Square Root of the AVE.

	PE	EE	SI	FC	HM	PV	HT	BI
PE	0.851845							
EE	0.505	0.855086						
SI	0.573	0.284	0.900843					
FC	0.595	0.706	0.404	0.70945				
HM	0.714	0.695	0.488	0.7012	0.775581			
PV	0.706	0.702	0.53	0.7042	0.7042	0.82619		
HT	0.701	0.498	0.581	0.618	0.677	0.712	0.729321	
BI	0.732	0.682	0.481	0.673	0.717	0.732	0.701	0.869526

Notes: PE-Expected performance, EE-Effort expectancy, SI-Social Influence, FC-Facilitating conditions, HM-Hedonic Motivation, PV- Price Value, HT-Habit, BI-Behavioral Intention

It is worth noting, however, that in the case of the FC construct and HM, PV and EE, these differences are very small, which may indicate that the FC construct is similar to them and therefore, the values of the AGFI and NFI coefficients for the model do not reach the threshold values (Tanaka, Huba, 1985).

The model presents relations between constructs, and the maximum likelihood method was used to estimate the model parameters. The model explains 81.4% of BI variability through changes in the estimated constructs.

Table 7. Structural Model Results.

Hypothesis	Beta	Error	t-value	p-value	Standardized Beta
H1: PE → BI	0.084	0.069	1.220	0.223	0.085
H2: EE → BI	0.221	0.069	3.223	0.001	0.237
H3: SI → BI	-0.028	0.031	-0.884	0.377	-0.042
H4: FC → BI	-0.120	0.124	-0.964	0.335	-0.075
H5: HM → BI	0.466	0.108	4.312	***	0.367
H6: PV → BI	-0.021	0.072	-0.290	0.771	-0.024
H7: HT → BI	0.353	0.061	5.785	***	0.466

Notes: PE-Expected performance, EE- Effort expectancy, SI-Social Influence, FC-Facilitating conditions, HM-Hedonic Motivation, PV- Price Value, HT-Habit, BI-Behavioral Intention

In the model, statistically significant relationships indicate a positive effect of HT, HM and EE on BI. The Standardization Beta was used as the strength of the influence, showing that the strongest influence is HT, then HM and finally EE.

Age moderation did not change the significance of the HM, HT and EE variables, but it did affect the significance of FC, whose impact on BI is negative, and PE, whose impact is positive.

In the group of women, the influence of EE on BI ceases to be significant. Only the influence of HT and HM is significant, while among men the influence of HM on BI ceases to be significant. Only the influence of EE and HT remains significant.

Experimental moderation did not affect the significance of EE and HT. However, it caused the influence of PE to be significant and positive, and the influence of FC and PV to be significant but negative.

DISCUSSION

The main goal of this study was to identify factors influencing the acceptance process of AI wearables, with particular emphasis on the current research issues of human and AI related technology. To understand this, replication studies were conducted within the UTAUT2 model. In particular, it was possible to confirm the impact of effort expectancy, hedonic motivation and habit on behavioral intentions to adopt AI Wearables. This is important for the new way of perceiving the human and AI related technology, as well as for the future shaping of scientific-research and implementation paradigms related to it.

Table 8. Structural Model Results – Hypothesis.

Hypothesis	Path	Comments
H1. Performance Expectancy positively affects the behavioral intentions to adopt AI Wearables.	PE → BI	Not supported
H2. Effort Expectancy positively affects the behavioral intentions to adopt AI Wearables.	EE → BI	Supported
H3. Social Influence positively affects the behavioral intentions to adopt AI Wearables.	SI → BI	Not supported
H4. Facilitating Conditions positively affects the behavioral intentions to adopt AI Wearables.	FC → BI	Not supported
H5. Hedonic Motivation positively affects the behavioral intentions to adopt AI Wearables.	HM → BI	Supported
H6. Price Value positively affects the behavioral intentions to adopt AI Wearables.	PV → BI	Not supported
H7. Habit positively affects the behavioral intentions to adopt AI Wearables.	HT → BI	Supported

The conducted research has confirmed that the habituation of consumers to the existing wearables solutions that they currently use is important for their future decisions regarding wearable devices enriched with elements of artificial intelligence. By using wearables, they have an established opinion about their current functionalities, they can assess their level of usefulness in their everyday life and identify those elements that could increase this level in the future. This seems to be fully justified, taking into account the fact that the general knowledge of consumers about a given technology has an impact on their level of perception of new solutions and the resulting acceptance behavior (Lin et al., 2007).

The research also indicated the importance of the enjoyment of using AI wearables, especially among women, who, as the previous research shows, are a group of consumers who are generally much more concerned about solutions based on new technologies, which was validated in earlier studies on the attitude to technology depending on by gender (Kim & Chiu, 2019). This may concern both the intuitiveness of use of these types of devices and the adaptation of the possibilities offered to actual expectations (Colgan et al.). This undoubtedly indicates a wide and varied area of factors that require further in-depth research and analysis, both in terms of their significance level and potential differences resulting from the variety of applications of available wearables, as well as the consumer profile.

The research also confirmed that the intention to adopt AI wearables is influenced by their perceived ease of use. Consumers expect this process to be as intuitive as possible. This applies to both direct interactions between the consumer and a given AI wearable device, especially at the beginning of the process, as well as the gradual acquisition of skills and proficiency in its use over time. Ease of use leads to a positive attitude of consumers, increasing their willingness to continue using this type of device (Chau et al., 2019). This raises the question to what extent are consumers of wearables prepared to popularize devices enriched with artificial intelligence and which elements associated with ease of use will be considered to be critical.

Also the results of the analysis of the influence of moderating variables: age, gender and experience on Behavioral Intention require further in-depth research, including, inter alia,

identification of situations in which the influence of these variables on individual variables of the construct could change (context).

LIMITATIONS

The publication is not free from cognitive, methodological and methodological limitations. However, it addresses new issues and the related new areas of their application, in line with the ongoing research on human and AI related technology. The conducted research has some limitations, which is a strong motivator for its further continuation and gradual deepening of knowledge in this field. This applies to both the research methods used (it would be advisable to include qualitative methods, including in particular the ethnographic ones) and the scope of the research conducted (broadening the spectrum of consumer behavior affected by AI wearables). Moreover, as mentioned earlier, the FC construct is similar to HM, PV and EE, which means that the value of the AGFI and GFI coefficients for the model does not reach the threshold values.

CONCLUSIONS

Digital technologies have now become a catalyst for subsequent stages of evolution, aimed at transforming the existing paradigms and solutions based on them. The literature review confirmed that these technologies have created a wide range of fascinating and previously unavailable possibilities. Artificial intelligence, as an element of customer support, is undoubtedly an exciting area of new interaction between human beings and technology, inextricably connecting with each other in a network of mutual digital connections and dependencies. However, many possibilities remain unknown, which results from their great diversity, complexity and the enormous dynamics of the technological changes taking place.

The AI wearables market is definitely at an early stage of development, leading to the gradual formation of augmented intelligence of the customer, and the process of social acceptance of these types of solutions requires much more than just a passing fascination. The shaping of conditions conducive to the acceptance of technologically advanced solutions must be based on understanding their essence and the nature of the human and AI relations, while being aware of the resulting challenges and limitations. It seems that the issues discussed in the study constitute a space for new research, including interdisciplinary and multicultural research, as well as may affect the processes of designing and testing AI wearable devices, accelerating the process of their commercialization and popularization.

IMPLICATIONS FOR RESEARCH, APPLICATION OR POLICY

Research Implications

The development of artificial intelligence and its implementation possibilities in every sphere of consumers' lives significantly increases the potential expectations towards it. This means the

need to identify the way in which a human interacts with devices based on this technology and to determine the factors determining its acceptance. The conducted research is an extension of the current authors' research and fits into the international discourse on the role of human and AI related technology, including in marketing. The analysis of the level of social acceptance of AI wearables based on the UTAUT2 model is in part a replication of existing global research in this field. The results obtained form the basis for further analysis of the determinants of social acceptance of technology, especially in relation to new constructs related to an increasing spectrum of consumer behavior as a result of their interaction with the technology, as mentioned in the Discussion section. There should be a focus on the conceptualization and systematic deepening of the impact of potential factors. It would be advisable to look for relationships that take into account the cultural differences of customers, which would allow for the possibility to find potential regularities and cause-effect relationships in the context of AI wearables acceptance.

Practical Implications

The market success of AI wearables depends on the level of acceptance of these types of solutions by consumers. The conducted research provides information that can support both the creators of wearables and employees of marketing departments. This applies to the design of AI wearables functionalities important for consumers, taking into account the expectations as to the technical parameters and quality of these types of devices, affecting their expected performance and ease of use. The recommendations resulting from the study are important from the point of view of designing functionalities of AI wearables that are significant for consumers, taking into account the expectations as to the technical parameters and quality of these types of devices. The research results can also provide guidelines for the optimization of marketing communication strategies implemented in this area, in order to be more effective, referring to the real consumer needs and expectations, while contributing to minimizing the significance of the concerns raised.

REFERENCES

- von Ahn, L. (2013). Augmented intelligence: the Web and human intelligence. *Philosophical Transactions of the Royal Society*, 371, doi:10.1098/rsta.2012.
- Alalwan, A.A., Dwivedi, Y.K. & Rana, N.P. (2017). Factors influencing adoption of mobile banking by Jordanian bank customers: extending UTAUT2 with trust. *International Journal of Information Management*, 37(3), 99-110, doi:10.1016/j.ijinfomgt.2017.01.002.
- Brown, S. A. & Venkatesh, V. (2005). Model of adoption of technology in households: A baseline model test and extension incorporating household life cycle. *MIS Quarterly*, 29(3), 399-426. doi:10.2307/25148690.
- Canhoto, A.I., Arp, S. (2017). Exploring the factors that support adoption and sustained use of health and fitness wearables, *Journal of Marketing Management*, 33(1-2), 32-60, doi: 10.1080/0267257X.2016.1234505
- Chau, K. Y., Lam, M. H., Cheung, M. L., Tso, E. K., Flint, S. W., Broom, D. R., Tse, G., & Lee, K. Y. (2019). Smart technology for healthcare: Exploring the antecedents of adoption intention of healthcare wearable technology. *Health Psychology Research*, 7(1), doi:10.4081/hpr.2019.8099

- Chen, Y.K. (2012), Challenges and opportunities of internet of things, paper presented at the 17th Asia and South Pacific design Automation Conference, January 30-February 2, Sydney, Australia.
- Chen, M., Ma, Y., Song, J., Lai, C. F., & Hu, B. (2016). Smart clothing: Connecting human with clouds and big data for sustainable health monitoring. *Mobile Networks and Applications*, 21(5), 825–845, doi:10.1007/s1103 6-016-0745-1.
- Cheung, M.L., Leung, K.S. & Chan, H.S.(2020). Driving healthcare wearable technology adoption for Generation Z consumers in Hong Kong. Young Consumers, *Emerald Publishing*, doi:10.1108/YC-04-2020-1123.
- Choi, J. & Kim, S. (2016). Is the smartwatch an IT product or a fashion product? A study on factors affecting the intention to use smartwatches. *Computers in Human Behavior*, 63, 777-786, doi:10.1016/j.chb.2016.06.007.
- Chuah, S.H., Rauschnabel, P.A., Krey, N., Nguyen, B., Ramayah, T. & Lade, S. (2016). Wearable technologies: the role of usefulness and visibility in smartwatch adoption. *Computers in Human Behavior*, 65, 276-284, doi: <http://dx.doi.org/10.1016/j.chb.2016.07.047>.
- Colgan, J. C., Bopp, M. J., Starkoff, B. E., & Lieberman, L. J. (2016). Fitness wearables and youths with visual impairments: Implications for practice and application. *Journal of Visual Impairment & Blindness*, 110, 335-348, doi: 10.1177/0145482X1611000505.
- Corrigan, J.M. (2012). Augmented intelligence-the new AI-unleashing human capabilities in knowledge work. In M. Glinz (Ed.), *Proceedings of the 34th International Conference on Software Engineering*. IEEE Press, Piscataway, 1285-1288.
- Crigger, E. & Khoury, C. (2019). Making policy on augmented intelligence in health care, *AMA Journal of Ethics*, Vol. 21(2), 188-191, doi:10.1001/amajethics.2019.188.
- Dierks, L.H., (2007). Does trust influence consumer behaviour? *Agrarwirtschaft* 56, 106-111.
- Dhiman, N., Arora, N., Dogra, N. & Gupta, A. (2020). Consumer adoption of smartphone fitness apps: an extendedUTAUT2 perspective. *Journal of Indian Business Research*, 12(3), 363-388, doi:10.1108/JIBR-05-2018-0158
- Esmaili, E., Desa, M.I., Moradi, H. & Hemmati, A. (2011). The Role of Trust and Other Behavioral Intention Determinants on Intention toward Using Internet Banking. *International Journal of Innovation, Management and Technology*, 2(1), 95-100, doi: 10.7763/IJIMT.2011.V2.111.
- Gabriel M. (2019). What does digital transformation really mean, <https://www.cio.com/article/3404876/what-does-digital-transformation-really-mean.html> [access: 19.10.2021].
- Gao, Y, Li, H. & Luo, Y. (2015). An empirical study of wearable technology acceptance in healthcare, *Industrial Management & Data Systems*, 115(9), 1704-1723, doi:10.1108/IMDS-03-2015-0087.
- Garattini, C., Raffle, J., Aisyah, D.N., Sartain, F. & Kozlakidis, Z. (2019). Big Data Analytics, Infectious Diseases and Associated Ethical Impacts, *Philosophy & Technology*, 32, 69–85, doi: 10.1007/s13347-017-0278-y.
- Gu, Z., Wei, J. & Xu, F. (2016). An empirical study on factors influencing consumers' initial trust in wearable commerce, *Journal of Computer Information Systems*, (56)1, 79-85, doi:10.1080/08874417.2015.11645804.
- Ertel, W. (2017). *Introduction to Artificial Intelligence*, Springer, Cham.
- Fang, Y. & Chang, C. (2016). Users' psychological perception and perceived readability of wearable devices for elderly people, *Behaviour & Information Technology*, 35(3), 225-232, doi:10.1080/0144929X.2015.1114145.
- Fornell, C. & Larcker, D. F. (1981). Structural Equation Models with Unobservable Variables and Measurement Error: Algebra and Statistics. *Journal of Marketing Research*, 18 (3), 382-388, doi: 10.2307/3150980.
- Hair J. F., Sarstedt M., Ringle C. Gudergan S. P. (2013). *Advanced Issues in Partial Least Squares Structural Equation Modeling*, Sage Publication.

- Hajo, A. & Galinsky, A.D. (2012). Encllothed cognition. *Journal of Experimental Social Psychology*, 48(4), 918-925, doi: 10.1016/j.jesp.2012.02.008.
- Hebbar, A. (2017). Augmented intelligence: enhancing human capabilities. In S. Bhattacharyya (Ed.), *Third International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN)*, IEEE, Piscataway, 251-254.
- Hoffman, D.L. & Novak, T. (2015), Emergent Experience and the Connected Consumer in the Smart Home Assemblage and the Internet of Things, Washington, DC.
- Holroyd, C. (2020). Technological innovation and building a ‘super smart’ society: Japan’s vision of society 5.0. *Journal of Asian Public Policy*, doi:10.1080/17516234.2020.1749340.
- Jarrahi, M.H. (2018). Artificial intelligence and the future of work: human-AI symbiosis in organizational decision making. *Business Horizons*, 61(4), 577-586, doi:10.1016/j.bushor.2018.03.007.
- Jouhki, J. (2020). The axes of the modern age. *Human Technology*, 16(1), 1-5, doi:10.17011/ht/urn.202002242160.
- Kalantari, M. (2017). Consumers’ adoption of wearable technologies: Literature review, synthesis, and future research agenda. *International Journal of Technology Marketing*, 12(3), 274-307, doi:10.1504/IJTMKT.2017.089665.
- Kamble, A., Desai, S. & Abhang, N. (2021). Wearable Activity Trackers: A Structural Investigation into Acceptance and Goal Achievements of Generation Z. *American Journal of Health Education*, 52(5), 307-320, doi:10.1080/19325037.2021.1955229.
- Kane, K. (2019). The technology fallacy - People are the real key to digital transformation. *Research - Technology Management*, 62(6), 44-49, doi:10.1080/08956308.2019.1661079.
- Kim, T. & Chiu, W. (2019). Consumer acceptance of sports wearable technology: the role of technology readiness. *International Journal of Sports Marketing and Sponsorship*, 20(1), 109-126, doi:10.1108/IJSMS-06-2017-0050.
- Kotler, Ph., Kartajaya, H. & Setiawan, I. (2021). *Marketing 5.0. Technology for humanity*. Jon Willey & Sons Inc. New Jersey.
- Lin, C.H., Shih, H.Y. & Sher, P.J. (2007). Integrating technology readiness into technology acceptance: the TRAM model. *Psychology & Marketing*, 24(7), 641-657, doi:10.1002/mar.20177.
- Li, J., Ma, Q., Chan, A.H. & Man, S. (2019). Health monitoring through wearable technologies for older adults: smart wearables acceptance model. *Applied Ergonomics*, 75, 162-169, doi:10.1016/j.apergo.2018.10.006.
- Lisboa, P.J. (2018), AI 2.0: augmented intelligence. In J. Liu, J., J. Lu, Y. Xu, L. Martinez & E.E. Kerre (Eds), *Data Science and Knowledge Engineering for Sensing Decision Support: Proceedings of the 13th International FLINS Conference (FLINS 2018)*, World Scientific Publishing, Singapore.
- Liu, D. & Guo, X. (2017). Can trust and social benefit really help? Empirical examination of purchase intentions for wearable devices. *Information Development*, 33(1), 43-56, doi: 10.1177/0266666916635724.
- Liu, X., Vega, K., Maes, P. & Paradiso J.A. (2016). Wearability Factors for Skin Interfaces, Proceedings of the 7th Augmented Human International Conference 2016, ACM Press, New York, 1-8, doi: 10.1145/2875194.2875248.
- Lunney, A., Cunningham N. & Eastin M. (2016). Wearable fitness technology: a structural investigation into acceptance and perceived fitness outcomes. *Computers in Human Behavior*, 65, 114-120, doi:10.1016/j.chb.2016.08.007.
- Mann, S. (2014). Wearable computing. In M. Soegaard & R.F. Dam (eds.), *The Encyclopedia of Human-Computer Interaction*, 2nd Ed. Aarhus, Denmark: The Interaction Design Foundation. Retrieved August 16, 2014, [in:] Mann, S. (2001). Wearable computing: Toward humanistic intelligence. *Intelligent Systems, IEEE*, 16(3), 10-15.

- Mewara, D., Purohit, P. and Rathore, B.P.S. (2016). Wearable devices applications and its future. *International Journal For Technological Research In Engineering, International Conference on Emerging Technologies in Engineering, Biomedical, Medical and Science (ETEBMS - 16)*.
- Muaremi, A., Arnrich, B. & Tröster, G. (2013). Towards measuring stress with smartphones and wearable devices during workday and sleep. *BioNanoScience*, 3(2), 172-183, doi:10.1007/s12668-013-0089-2.
- Nascimento, B., Oliveira, T., & Tam, C. (2018). Wearable technology: What explains continuance intention in smartwatches? *Journal of Retailing and Consumer Services*, 43, 157–169, doi:10.1016/j.jretconser.2018.03.017
- Oinas-Kukkonen, H. (2013). A foundation for the study of behavior change support systems. *Personal and Ubiquitous Computing*, 17, 1223–1235, doi:10.1007/s00779-012-0591-5.
- Oh, J.& Kang, H. (2021). User engagement with smart wearables: Four defining factors and a process model. *Mobile Media & Communication*, 9(2), 314 –335, doi:10.1177/2050157920958440.
- Panetta, K. (2019), Gartner Top Strategic Predictions For 2020 And Beyond, <https://www.gartner.com/smarterwithgartner/gartner-top-strategic-predictions-for-2020-and-beyond> [access: 03.10.2021].
- Pasquinelli, M. (2015). *Alleys of Your Mind: Augmented Intelligence and its Traumas*. Meson Press, UK.
- Park, S., Chung, K., & Jayaraman, S. (2014). Wearables: Fundamentals, advancements, and a roadmap for the future. In E. Sazonov & M. R. Neuman (Eds.), *Wearable sensors*, Academic Press, 1-23.
- Rieder, A., Eseryel Y.U., Lehrer, C. & Jung R. (2021). Why Users Comply with Wearables: The Role of Contextual Self-Efficacy in Behavioral Change. *International Journal of Human - Computer Interaction*, 37(3), 281-294, doi:10.1080/10447318.2020.1819669
- Rimol, M. (2021). Gartner Forecasts Global Spending on Wearable Devices to Total \$81.5 Billion in 2021, <https://www.gartner.com/en/newsroom/press-releases/2021-01-11-gartner-forecasts-global-spending-on-wearable-devices-to-total-81-5-billion-in-2021> [access: 19.10.2021].
- Rold, A.C. (2019). The Future of AI is Intelligence Augmentation, <https://www.diplomaticourier.com/posts/the-future-of-ai-is-intelligence-augmentation> [09.10.2021].
- Russell, S., Norvig, P. (2016). *Artificial Intelligence: A Modern Approach*. Pearson Education Limited, Malaysia.
- Sachini, N. K., Arachchige, K., Burch V, Chander, H., Turner A.J. & Knight A.C. (2021). The use of wearable devices in cognitive fatigue: current trends and future intentions. *Theoretical Issues in Ergonomics Science*, doi:10.1080/1463922X.2021.1965670.
- Sharma, M. (2019). Augmented intelligence: a way for helping universities to make smarter decisions. In V.S. Rathore, M. Worrington, D.K. Mishra, A.Joshi & S. Maheshwari, S. (Eds), *Emerging Trends in Expert Applications and Security*, Springer, Singapore, 89-95.
- Shin, G, Jarrahi, M.H., Fei, Y., Karami, A., Gafinowitz, N., Byun, A. & Lu, X. (2019). Wearable activity trackers, accuracy, adoption, acceptance and health impact: a systematic literature review. *Journal of Biomedical Informatics*, 93, doi:10.1016/j.jbi.2019.103153.
- Tanaka, J.S., Huba, G.J., (1985). A fit index for covariance structure models under arbitrary GLS estimation. *British Journal of Mathematical and Statistical Psychology*, 38, 197–201, doi.org/10.1111/j.2044-8317.1985.tb00834.x
- Vaitkevičius, S., Mažeikienė, E., Bilan, S., Navickas, V., & Savanevičienė, A. (2019). Economic demand formation motives in online-shopping. *Inžinerinė ekonomika*, 30(5), 631-640.
- Venkatesh, V., Thong, J. Y. L. & Xu, X. (2012). Consumer acceptance and use of information technology: Extending the unified theory of acceptance and use of technology. *MIS Quarterly*, 36(1), 157-178.

- Venkatesh, V., Morris, M.G., Davis, G.B. & Davis, F.D. (2003). User acceptance of information technology: toward a unified view, *MIS Quarterly*, 27(3), 425-478.
- Venkatesh, V. & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science*, 46(2), 186-204, doi:10.1287/mnsc.46.2.186.11926.
- Wright, R., Keith, L. (2014). Wearable technology: If the tech fits, wear it. *Journal of Electronic Resources in Medical Libraries*, 11(4), 204–216, doi: 10.1080/15424065.2014.969051.
- <https://www.statista.com/topics/1556/wearable-technology> [access: 19.10.2021].
- Wang, L., Rau, P. L. P., & Salvendy, G. (2011). Older adults' acceptance of information technology. *Educational Gerontology*, 37(12), 1081-1099. doi:10.1080/03601277.2010.500588.
- Wearable Devices Market Share, <https://www.idc.com/promo/wearablevendor> [access: 19.10.2021].
- Xiong, J., Chen, J. & Lee, P.S. (2021), Functional Fibers and Fabrics for Soft Robotics, Wearables, and Human-Robot Interface, *Advanced Materials*, 33(19), doi:10.1002/adma.202002640.
- Xia, C. & Maes, P. (2013). The design of artifacts for augmenting intellect. In *Proceedings of the 4th Augmented Human International Conference*, 154-161, doi: 10.1145/2459236.2459263.
- Yang, H., Yu, J., Zo, H. & Choi, M. (2016). User acceptance of wearable devices: an extended perspective of perceived value. *Telematics and Informatics*, 33, 256–269, doi:10.1016/j.tele.2015.08.007.

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Human Technology
ISSN 1795-6889
<https://ht.csr-pub.eu>

VIRTUAL REALITY-BASED COGNITIVE STIMULATION USING GRYDSEN SOFTWARE AS A MEANS TO PREVENT AGE-RELATED COGNITIVE-MOBILITY DISORDERS – A PILOT OBSERVATIONAL STUDY

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Abstract: *The human aging process is associated with systematic deterioration of cognitive and motor performance. Age-related deficits in motor skills and symptoms of cognitive decline, such as memory, attention and executive functioning problems, are major contributors to a loss of functional independence and reduced quality of life of the elderly. The virtual reality system presented can be used as an aid for effective training of those skills. The use of virtual reality training for therapeutic purposes is promising – not only does it provide encouraging medical and psychological effects but it may also be considered as an interesting leisure activity for seniors. The paper presents a pilot study which aims to qualitatively assess the usefulness of a VR technology-based solution for training cognitive and motor functions. The pre-test phase of the study was conducted on 9 subjects aged 62-81 ($M = 71.66$; $SD = 7.00$), who were asked to evaluate the performed tasks in terms of novelty and attractiveness. All subjects completed the pilot study. The SUS result was 55.56 ($SD = 9.90$), which is a marginal result. However, the UEQ result showed that all aspects of the game were reported as satisfactory. The pilot studies show that VR is well tolerated by the elderly. As demonstrated by the results, the system has moderate utility, but may be a promising solution for training cognitive-motor skills.*

Keywords: *virtual reality, cognitive training, motor training, elderly, cognitive decline, rehabilitation.*

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DOI: <https://doi.org/10.14254/1795-6889.2021.17-3.7>



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INTRODUCTION

The problem of cognitive decline in the elderly

The world's population is aging at an unprecedented rate. A systematic increase of human life expectancy carries with it specific social, economic and health consequences. It is forecasted that the number of elderly people will more than double in the near future, reaching over 1.5 billion in 2050 (United Nations Department of Economic and Social Affairs, Population Division, 2020). With the accelerated aging of the population, the incidence of age-related disorders, including cognitive and motor dysfunctions, will also continue to increase (Peng et al., 2019).

As people grow older, there is a gradual decline in cognitive functions. This process is referred to as cognitive aging (Harada et al., 2013). However, not all cognitive functions are equally affected by age-related changes. Some aspects of memory and attention are particularly sensitive to the effects of aging (Glisky, 2007). In terms of memory, the greatest involutinal changes are observed for episodic memory, working memory and the encoding of new information in long-term memory (Grady, 2008; Murman, 2015). In terms of attention, the functions that deteriorate most with age are selectivity, divisibility and shifting. In addition, higher-order cognitive functions, such as linguistic processing and decision-making, may also be impaired. However, the key factor contributing to the deterioration of cognitive functioning in late adulthood is the impairment of executive functions that progresses with age (Glisky, 2007). Age-related deficits in cognitive skills may gradually affect an individual's ability to function effectively in everyday life, thus contributing to social withdrawal.

As the number of individuals with age-related cognitive disorders and motor problems is expected to increase significantly during the next 30 years, it is necessary to actively seek innovative training methods to slow down the side effects of aging and, consequently, support the maintenance of functional independence of seniors.

The problem of motor disorders in the elderly

The aging process gradually impacts one's ability to perform daily functional activities. These limitations are associated with changes in the neuromuscular system, which include reduced muscle strength, power, endurance and increased fatigability. As argued by Hunter et al., these limitations are related to changes in motor units (Hunter, Pereira, Keenan, 2016). Additionally, another age-related problem is the reduction in the range of joint mobility, partly due to changes in the connective tissues (Freemont, Hoyland, 2007; Yamada, et al., 2002). This makes it difficult to perform motor activities. The motor performance of the elderly is also impaired due to disturbed anticipatory motor planning. Stockel et al. suggest that anticipatory motor planning abilities are strongly influenced by cognitive control processes, which seem to be the key mechanisms to compensate for age-related decline (Stöckel, Wunsch, Hughes, 2017).

The use of VR to improve cognitive and motor functioning in the elderly

The use of virtual reality (VR) offers many new possibilities in the field of intervention and broadly understood therapy for older adults. Compared to traditional interventions based on the paper-and-pencil method, VR training offers the possibility of flexible adaptation of exercises to the needs and cognitive abilities of the patient (Coyle et al., 2015). In addition, training of this type is characterized by ecological accuracy. This means that the tasks performed refer to the skills used in everyday life. Another advantage of VR training is that it allows the users to explore the environment on their own. This has a positive effect on the development of self-efficacy and a sense of independence during therapy. An additional advantage is the possibility to incorporate the gamification factor, which results in an increased level of motivation and commitment to training (de Bruin et al., 2010).

The conclusions from the systematic literature review indicate that the use of computerized or VR-based cognitive training in the elderly gives comparable or better effects in terms of improving cognitive functions compared to traditional methods (Zajac-Lamparska et al., 2019). Research data show improvements in executive function, attention, visual memory, and long-term memory in people who have undergone VR training (Gamito et al., 2020; Optale et al., 2010). There are also more reports indicating the high effectiveness of VR in the training of motor functions (Lee, Lee, Song, 2018; Calabro et al., 2017; Molhemi et al., 2020). Taking into account the cited data, it can be concluded that the use of VR is an effective method of cognitive training.

Difficulties in functioning in VR in the elderly

The research conducted so far shows that VR is well tolerated by the elderly (Lin, Lee, Lally, Coughlin, 2018; Syed-Abdul et al., 2019; Benoit et al., 2015; Wojciechowski et al., 2021). The study of Benoit et al. highlighted that those participants did not experience sickness during the experiment across the VR conditions (Lin, Lee, Lally, Coughlin, 2018). Syed-Abdul S. et al. conclude that participants of their study perceived VR as a beneficial, user-friendly and enjoyable experience, implying positive attitudes toward adopting this new technology.

However, it is worth noting that the positive attitude of older people towards new technologies and virtual environments is verified by their real functionality. Improperly designed application or environment can discourage users despite their initially positive attitude.

Older people perceive color contrast differences less efficiently, especially in the area of blue-green tones. For this reason, it is necessary to rely mainly on the luminance of colors (C. Owsley et al., 1983). Additionally, colors should be used according to expectations and accepted conventions, e.g. red means "stop" while green means "go".

Since the visual field of older people is narrower, the area of interest should be focused as close to the center of the visual field as possible (Cerella, 1985). For example, interface elements should be concentrated in the center of the display. Graphics should be kept as simple as possible to eliminate distractors, such as animation, patterns on walls, and glowing text (W. Kosnik et al., 1988). Typically, older people have poorer vision and worse ability to see details, so interface elements, including text, should be larger and more legible. Gaze

control or the use of gaze to interact with the environment is also limited. Inexperienced users explore the scene space quite nervously and impulsively with their eyes. As a consequence, using gaze as an input interaction channel can be ineffective (Wojciechowski et al., 2014).

An important component of a virtual reality system is the auditory stimuli. However, it should be remembered that the ability to recognize sounds of different frequencies decreases with age. Sounds above 2500 Hz are usually inaudible (Berkowitz J.P. et al., 1990) so instructions and other auditory events should refer to lower frequencies. The frequency range between 500 and 1000 Hz is considered optimal for older users.

Memory performance is strictly related to the simplicity of tasks conducted by elderly people. No more than 5 ± 2 related items should be presented on the display panel. The elderly use long-term memory much more effectively than short-term memory. In consequence, their ability to recall something from experience is much better than learning something new. Thus, user interface design should focus on using functions or graphics that may rely on the functions on those instruments learnt in the past. Commands should be straightforward and not create confusion to the user to prevent them from possible misunderstanding and losing recognition of the functions in the short term.

Physical decline is an additional problem affecting older users' interaction with computer systems. Seniors may have problems with the response speed rather than complexity of use. Fisk et al. (2020) reported difficulties in the use of double click, but when interval time was increased, the difficulties appeared to be lower. Older users may have difficulties finding small targets in an interface and performing movements with high accuracy (Andrzejczak et al., 2021). Hand-controlled interfaces can be excessively challenging for older users because of the lack of precision of movement, individual differences in movement characteristics, and the lack of adequate visual feedback (Pórola et al., 2012).

All the above findings suggest that seniors may find it difficult to interact in a virtual environment that was not designed specifically for them. Having in mind all the above issues and considering the promising findings of cognitive rehabilitation (Zajac-Lamparska et al., 2019) a new gamified virtual reality environment was designed and implemented, which may serve both cognitive stimulation and physical rehabilitation purposes.

MATERIALS AND METHODS

Purpose

Due to the specificity of immersive training dedicated to the elderly, and the desire to create a game that would suit seniors both technically and qualitatively, we asked the senior players detailed research questions before implementing the full version of the interface.

As part of a varied pilot study of the GRYDSEN interface, we want to check whether:

- game scenarios are correctly formulated,
- the interface is adapted to the needs of the elderly,
- the instructions are exhaustive enough for the audience.

In addition, we want to qualitatively check whether the respondents understand the game, their interest, opinion and the way they react to selected scenarios.

Participants

The study was conducted in 2021. Participation in the study was voluntary, people who had signed informed consent to participate in the project were enrolled immediately. Only adults over 60 years of age participated in the study, with no upper age limit. All participants were informed that they could withdraw from the study at any stage. Only full questionnaires were included in the analysis. The pilot study was conducted on a purposefully selected sample – 9 people over 60 years of age. People with contraindications to VR games were excluded from the study. In addition, the inclusion criterion was the lack of cognitive impairment (MMSE > 27 points) (Nitrini et al., 1994).

Ethical Considerations

The study was approved by the Bioethics Committee of the Nicolaus Copernicus University Collegium Medicum in Bydgoszcz, Poland (KB 426/2021). The research was conducted in accordance with the Helsinki Declaration. All participants provided informed consent for the research.

Outcome measures

Before proceeding with the pilot study, all potential participants completed an introductory interview assessing the inclusion criteria. The interview consisted of two parts. The first one referred to the sociodemographic data, such as age, gender, place of residence, marital status, educational level, number of years of study, acquired profession, and professional status. The second part referred to the basic information related to the health status, such as previous head injury, concussion, or meningitis, experiencing epilepsy, stroke, dizziness, motion sickness, or any somatic or mental diseases. The questions concerning hearing or musculoskeletal system impairment and physical activity were also included.

The three evaluation sheets of game tasks were self-constructed. They assess the user experience of cognitive, motor, and motor-cognitive tasks and provide a subjective view of their accessibility.

The motor task evaluation sheet consists of 6 items rating from 0 to 10. They refer to the evaluation of graphic design, safety, clarity of the statements, task difficulty level, time dedicated to solving the task, fatigue, level of immersion and ease of attendance. The other comments or suggestions are also included. The cognitive task evaluation sheet consists of 7 items rating from 0 to 10. They evaluate the number of tasks included, time dedicated to solving the task, clarity of statements, task difficulty level, readability of the displayed text and graphic design, and usefulness of the hints. The possible comments are also included. The cognitive-motor task evaluation sheet consists of 7 items rating from 0 to 10. The construction of this task allowed the usage of the previous, cognitive task evaluation sheet. All items, except the item concerning the hints, are the same.

The User Experience Questionnaire (UEQ) (Laugwitz, Schrepp, Held, 2008) is a fast and reliable questionnaire to measure the user experience of a product. It consists of 6 scales with 26 items with seven response options. The scales refer to attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty.

The System Usability Scale (SUS) (Brooke, 1986) is a scale concerning subjective assessments of the usability of a product. It consists of 10 items with five response options: from strongly agree to strongly disagree. The scale is widely used and provides a high-level subjective view of usability. The score ranges from 0 to 100.

GRYDSEN

As part of the GRYDSEN project, separate modules for training the cognitive, motor and cognitive-motor functions were developed. As part of the pilot study, three scenarios were tested, one for each of the modules replaced (Fig. 1).

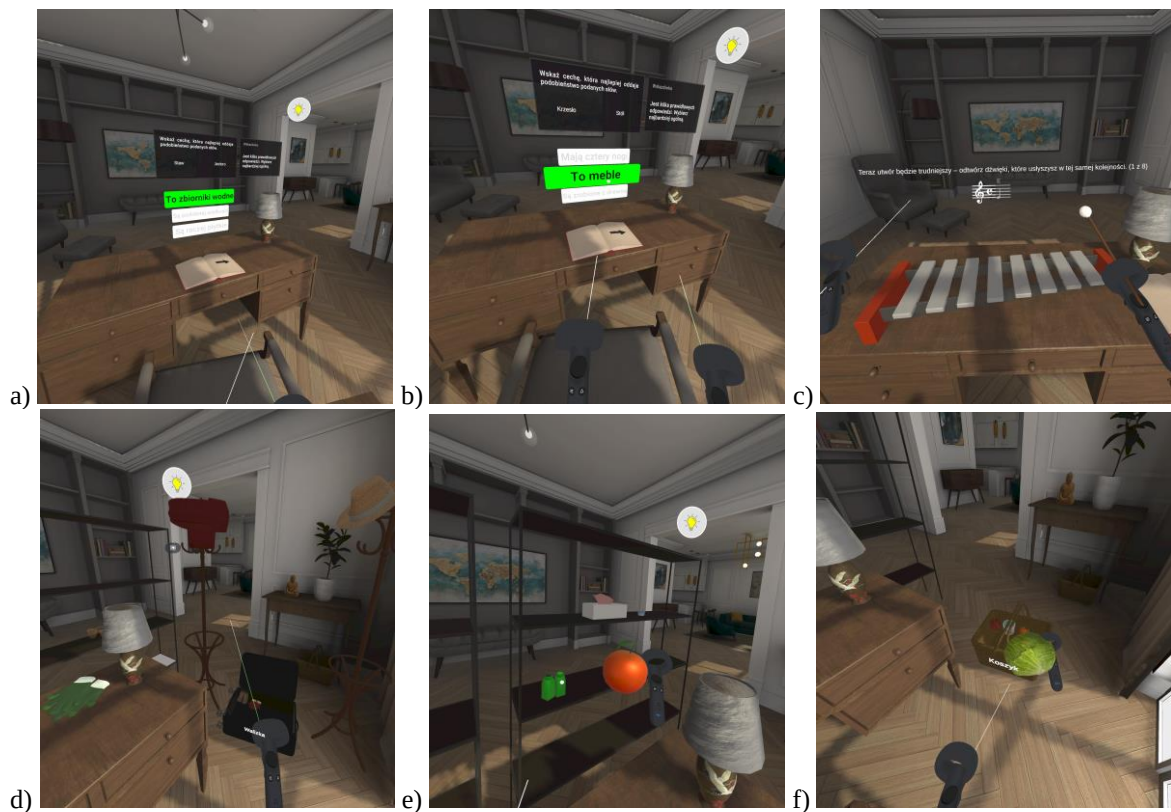


Figure 1. The GRYDSEN cognitive, motor and cognitive-motor modules. a), b) - ANALOGIES (cognitive), c) - XYLOPHONE (motor) and d), e), f) - EVERYDAY ACTIVITIES (cognitive-motor) modules previews from user (VR headset) perspective.

Overall, the scenes, and their equipment, were designed to meet the aforementioned guidelines for designing virtual environments for the elderly. Appropriate color scheme (background objects in gray colors, interactive objects of appropriate size and color/brightness contrast), appropriate readability of text commands, the appropriate number of interactive objects, lack of details and distractors, clear way of object selection supplemented with both visual and audio feedback are only the main of many procedures for improving the usability and functionality of the tested VR environment.

Cognitive functions module: The ANALOGIES task has been created for the training of cognitive functions. The implemented project assumes that the scenarios from the "Cognitive Training" module will primarily involve attention, executive function and memory (operational, long-term, retrospective, prospective). The pilot study focused on inference by analogy. Tasks of this type refer to the ability of an individual to detect the relationship between different objects and the ability to use the same inference / problem-solving schemes under different conditions. The skill training inferred by analogy is especially recommended to stimulate the attention function. Reasoning by analogy covers a wide class of tasks. The described scenario included tasks that required the participant, among others, the ability to point out opposites and similarities, identify words that were related to non-semantic features (e.g. similar spelling, rhyme) or related to objects that belonged to the superior class or had common property. The use of VR required a modification of the classic form of this task, in which the tested person formulates an answer themselves. The scenario was created in such a way that the examined person chooses the answer that best suits them from a catalog of options.

At the very beginning, the user is acquainted with the command and then, using the controller, selects the feature label that best describes the selected objects. The task is repeated several times, for different sets of objects, after which the number of correct answers is recorded. A prolonged lack of the user's response causes the prompt to appear, and the user has an independent option to use the prompt – a light bulb icon in the corner of the screen.

Motor functions module: The task is to strike certain calves of the XYLOPHONE with the sticks. It helps to improve gross and small motor function and involve various muscle groups. In addition, the exercise requires appropriate coordination and precision of movement. The user, standing in front of the xylophone and holding the sticks in his hands (controllers), should play a sequence of sounds. The melody to be played is not only sequentially displayed as notes on a music stave, but also the individual xylophone calves are highlighted in color. The span of xylophone calves and the choice of sounds and length of the sequence itself directly affects the range of upper limb mobility, as well as stimulating short-term memory. In a situation of prolonged thinking, the user has the option to listen to the sequence of sounds again or can get help by clicking on the light bulb icon in the upper right corner of the interface.

Module cognitive-motor functions: The essence of the module is the involvement of cognitive functions (here: memory, attention) and motor functions. The described part of the game concerns both the simulation of everyday life (ecological paradigm) as well as tasks directly used in training the cognitive functions of aging people. The player will be tasked with performing everyday activities. As part of the pilot study, the EVERYDAY ACTIVITIES task and shopping task was tested (Fig. 1). The player's task was to choose items that would be expected, either useful or required, depending on the task. The choice of objects depends on the time of year, leisure activities or an actual shopping list. From the interface, it required reading a command, augmenting conditions or remembering products list and selecting adequate objects. In the case of packing, exemplary staying at the beach in July or visiting a city in autumn, implied a specific set of staff to be selected (Fig 1d). The shopping task required choosing items from the list that needed to be remembered. The puzzle was constructed in such a way as to have several levels of difficulty, i.e. through increasing the number of objects to be selected. The items needed for the trip or to shop were

spread all over the room so that the player had to look around the room and "reach" for them. They remained within the player's reach all the time, but their distribution was randomly redistributed within each scenario try. At the very bottom of the screen, you could see a representation of the bag or the shopping cart in which the user had to pack the staff (Fig. 1f). The objects, the suitcase, and the cart to which they were to be put were placed in the room in such a way that the user had to look around activating the upper body part. Additionally, pointing to the objects with the controller pointer as well as placing the objects in the suitcase/basket required moving the upper limbs, which stimulated motor functions. The user could both operate the environment while standing and seating, which prevented loss of balance and increased safety for the participants immersed in VR.

RESULTS

Participants

We recruited 9 people, 5 men and 4 women, to take part in our pilot study. The subjects were aged 62-81 ($M = 71.66$; $SD = 7.00$). In the group of respondents, 5 people had higher education and 4 had secondary education background. The average year of education was $M = 15.11$. All respondents were urban dwellers. The subjects did not suffer from any neurological diseases, serious somatic diseases, or mental disorders. One person declared that he was dizzy. All subjects had a visual impairment, two of them had a hearing impairment.

Assessment of individual tasks

Table 1 summarizes the participants' responses to the Analogies task. The conducted analyzes show that the participants highly rated such aspects of the task as the number of tasks, the time needed to complete them, the readability of the text and the readability of the graphic elements. The respondents assessed the usefulness of the formulated hints as low since the tasks were clear. The degree of difficulty of the tasks was assessed as average.

Table 1. Questions evaluating ANALOGIES tasks.

Questions	M	SD	Min	Max
1. Number of tasks: On a scale of 0 to 10, how would you rate the number of examples in this task?	8.44	1.24	6.00	10.00
2. Execution time: On a scale of 0 to 10, how do you rate the time needed to complete this task?	8.89	0.78	8.00	10.00
3. Clarity and unambiguity of the instructions for performing a task: How do you evaluate the instruction for a task on a scale from 0 to 10? Is it unambiguous?	5.56	1.13	4.00	8.00
4. Task difficulty rating: How would you rate the task difficulty on a scale from 0 to 10?	4.89	1.36	3.00	7.00
5. Evaluation of the usefulness of the hints: How, on a scale from 0 to 10, do you assess the usefulness of the formulated hints?	4.89	0.60	4.00	6.00
6. Readability of the displayed text: How do you assess the readability and/or visibility of the displayed text on a scale from 0 to 10?	8.78	0.97	7.00	10.00
7. Readability of displayed graphic elements: How do you assess the readability of displayed graphic elements on a scale from 0 to 10?	8.89	1.05	7.00	10.00

Note: M – mean; SD – standard deviation; Min – minimum value; Max – maximum value.

Table 2 lists the participants' responses to the Everyday activities task. The conducted analyzes show that the participants highly rated such aspects of the task as: the number of tasks, the time needed to complete them, the clarity of the formulated instructions and usability. This task was rated as difficult by the users. Moreover, the respondents assessed the readability of the text and the graphic elements as low.

Table 2. Questions evaluating of EVERYDAY ACTIVITIES tasks.

Questions	M	SD	Min	Max
1. Number of tasks: On a scale of 0 to 10, how would you rate the number of examples in this task?	9.33	0.71	8.00	10.00
2. Execution time: On a scale of 0 to 10, how do you rate the time needed to complete this task?	9.33	0.71	8.00	10.00
3. Clarity and unambiguity of the instructions for performing a task: How do you evaluate the instruction for a task on a scale from 0 to 10? Is it unambiguous?	9.00	0.87	8.00	10.00
4. Task difficulty rating: How would you rate the task difficulty on a scale from 0 to 10?	8.44	1.33	6.00	10.00
5. Readability of the displayed text: How do you assess the readability and/or visibility of the displayed text on a scale from 0 to 10?	5.89	0.78	5.00	7.00
6. Readability of displayed graphic elements: How do you assess the readability of displayed graphic elements on a scale from 0 to 10?	4.11	1.05	3.00	6.00
7. Usefulness: On a scale from 0 to 10, how would you rate the usefulness of the task performed?	8.56	1.01	7.00	10.00

Note: M – mean; SD – standard deviation; Min – minimum value; Max – maximum value.

Table 3 summarizes the participants' responses to the Xylophone task. The conducted analyzes show that the participants highly rated such aspects of the task as the level of safety during the performance of the task and the level of difficulty of the task. The users evaluated the graphic design and the brightness of the task as average. The level of fatigue during the performance of the task was assessed as low. Moreover, the respondents assessed the motor task as quite difficult to perform.

Table 3. Questions evaluating of XYLOPHONE tasks.

Questions	M	SD	Min	Max
1. Graphic design	6,78	0,97	5,00	8,00
2. Safety (did you feel safe while performing the tasks?)	8,22	0,83	7,00	9,00
3. Clarity of tasks	6,78	1,39	5,00	9,00
4. Task difficulty level	7,89	0,93	6,00	9,00
5. Time dedicated to solving the task	5,67	1,00	5,00	8,00
6. Fatigue / Exercise Level	2,56	1,01	1,00	4,00

Note: M – mean; SD – standard deviation; Min – minimum value; Max – maximum value.

System Usability Scale

The mean of the evaluation of GRYDSEN software in the pilot study using the SUS scale was 55.56 (SD = 9.90). The minimum user rating was 40, and the maximum was 70. According to the table designed by Bangor, the average project value in the ratings of the testers belongs to the categories “ok” and “good”, which is in the range of 50-70 (Bangor, Kortum & Miller, 2009). This result means that GRYDSEN software still has room for improvement.

User Experience Questionnaire

The evaluation of the application carried out with the use of the UEQ tool shows that all assessed aspects of the game stimulating cognitive and motor functions are good (all results above +0.80) (Fig. 2). The respondents highly rated the attractiveness (M = 1.87), stimulation (M = 1.69), and novelty (M = 1.61). Some aspects of the game such as dependability (M = 1.41), efficiency (M = 1.16) and perspicuity (M = 0.92) were assessed slightly lower.

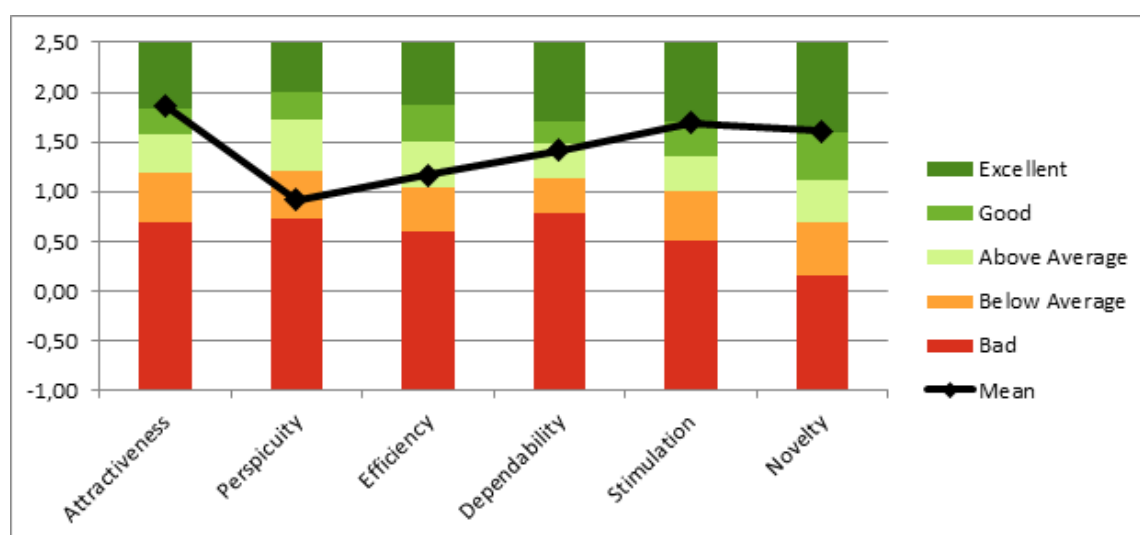


Figure 2. User experience feedback measured on the six UEQ scales for the whole application.

DISCUSSION

The goal of this study was to assess the usability and user's experience of a VR cognitive-motor training system for the elderly. As the rate of aging societies is rapidly increasing, a growing number of age-related disorders will also be observed. This creates the need for solutions that could help strengthen and support the cognitive and motor skills of the elderly (Doniger et al., 2018). The virtual reality system can be used as a platform for effective training of those skills. Virtual reality offers physical and mental benefits for older adults, while also providing entertainment. Moreover, VR is ecologically valid and enables the simulation of daily living activities (Pedroli et al., 2018; Banville et al., 2017). The results of the performed pilot study, concerning the System Usability Scale (55.56, SD = 9.90) and the

User Experience Questionnaire (all results above +0.80) scores, showed that our system can forecast as a fully-flagged cognitive-motor training alternative. The pilot study itself becomes a basis for evaluation as well as improving quality and usability of the system interface. Implementation of the Grydsen improvements will further increase the usability of the system in motor-cognitive exercises in older adults.

The user experience of the system

The SUS score was 55.56 (SD = 9.90), which is a marginal score. However, the UEQ score showed that all aspects of the game were reported as satisfactory. The innovative design of the system does not allow us to compare it with similar systems, especially in terms of user experience. The authors of this study did not find in the literature parallels to the GRYDSEN software, as other researchers focus more on patients with selected diseases than on normally aging adults. In addition, the few available interfaces cover related scopes of the presented tasks, i.e. cognitive, motor and cognitive-motor tasks, in particular those that require the player to multitask. None of the solutions presented in the literature to date has simultaneously addressed so many cognitive-motor modalities and has been implemented with attention to such an in-depth analysis of the needs of older adults. An interesting project dedicated to aging adults is that by Tuena et al. (2020), who conducted a systematic review of usability issues of clinical and research applications of virtual reality in older people. Although this study focused mainly on physiotherapy training, it reported that VR systems are good, well-accepted, adequate, effective, and useful. The authors claim that the skepticism of the elderly concerning digital systems could be successfully reduced by longer exposure to VR. Huygelier et al. (2019) reported that older adults who never had prior experience with VR had a neutral attitude towards this technology. Our pilot study showed similar experiences – despite the anxiety about experiencing the novelty, the elderly responded very positively and declared their willingness to continue participating in the project. Among most of these people, there was a suggestion that people who have never had contact with the VR system should be provided with a tutorial, where they can slowly learn how to navigate this interface. In addition, some of the participants indicated that they would prefer to have wider descriptions of tasks, and several users declared the need to have the tasks read by the teacher. On the part of the players, however, it was not an obstacle to complete all the tested tasks one after another. An additional advantage mentioned by almost all participants was the possibility of simultaneous cognitive-motor training. Moreover, they became more positive after the first exposure to a virtual-reality system. It is a very promising result, which demonstrates that VR systems could be widely used among the elderly for comprehensive training.

Cognitive-motor tasks

The analysis of cognitive-motor tasks questionnaires showed that, in general, most tasks were positively evaluated. Despite the positive results, several issues could be improved during further evaluation. As shown in the reports obtained from cognitive-motor tasks and the qualitative reports, some features could be modified. In the qualitative report, participants claimed that adding a tutorial before starting the game could be a profitable solution. Some

aspects concerning the manual usage of the VR system were underlined. The participants claimed that it was hard to catch the elements, especially in the motor task. They also stated that in the cognitive-motor task added hints could make the task more readable. Doniger et al. (2018) created a virtual reality-based cognitive-motor training for middle-aged adults at high Alzheimer's disease risk. The study involved simulation of daily activities, such as a virtual supermarket. The participants reported that adding training before the exercise could be an easy-to-use solution to avoid other problems. It proves that such tutorials could contribute to the easier perception of the virtual reality system for the elderly who had no prior experience with VR. Moreover, it could resolve other difficulties concerning system usage.

Importantly, the tasks included in the training relate to daily life activities, which makes the system ecologically valid. Moreover, the usage of VR systems improves the immersion of participants. Mrakic-Sposta et al. (2018) created physical and cognitive training which included riding a bike in a park, crossing roads-avoiding cars, and making grocery shopping in a supermarket. They proved that participants showed a greater improvement in the executive test, memory, and verbal fluency functions. This evidence suggests that cognitive-motor training could prevent or slow a person's cognitive decline with age.

Future works and limitations

Virtual reality systems represent a promising technological solution that could be easily implemented as part of a cognitive-motor rehabilitation program for the elderly. Previous studies confirm that such training can result in an improvement of both motor and cognitive skills, but also support everyday functioning of older adults (Mrakic-Sposta et al., 2018; Kannan et al., 2019; Gamito et al., 2020; Faria et al., 2016). The inclusion criteria in our pilot study were the lack of cognitive impairment. However, the introduction of the VR system to clinical practice, considering both the healthy group and pathology-related complications, could have the potential for usability (Lin, Lee, Lally, Couhlin, 2018; Syed-Abdul et al., 2019). Previous research (Doninger et al., 2018; Kannan et al., 2019; Faria et al., 2016) proved that using virtual reality based-training could be widely used in patients with Alzheimer's disease risk or with chronic stroke.

Different issues related to the software have been highlighted by the participants. These topics are reserved for future work. Further studies will take into account adding a tutorial before an exercise, as suggested by the participants. One downside regarding the pilot study is that it includes a limited number of participants. In any case, the homogeneity of information obtained from the interviews permits us to hypothesize that numerous other critical variables would not affect our findings when tested with a greater number of subjects. Another potential limitation is related to the problem of cybersickness that may occur during exposure to VR environments (Cobb, Ramsey, Wilson, 1999). However, our VR tasks are designed to minimize this risk. The cognitive-motor training system presented has been proven to be well-accepted by the participants.

The results of user interface testing pointed to the need for a slight adaptation of the size of objects and the scale of the environment itself. The use of a wide-angle camera, which increases the field of view, implies the need to slightly enlarge objects that were perceived as too small in their original size. The reported problems with remote object selection (exploiting ray casting) were solved by increasing the sensitivity area assigned to the selected

objects and moving them slightly away from each other. Therefore, the designed interface was received very positively.

A few users pointed to the need to implement mechanisms to calibrate the VR environment space to the averaged preferences of different users. The operation of the hardware interface (HTC Focus Plus with dedicated controllers) proved to be smooth and intuitive for the proposed scenarios. The core functionality of HTC devices was used to make the process of learning and using VR controllers as simple as possible. The ease with which the users familiarize themselves with both the hardware and the environment demonstrates its high accessibility and intuitive use.

CONCLUSIONS

The pilot study showed the advantages of the Grydsen software, while also indicating the areas that need improvement. Appropriate modifications will be made in the next stages of the project. This will help to achieve greater usability and functionality of the software presented. What is important, our pilot study showed that despite initial concerns about the virtual reality environment, the elderly responded very positively and declared their willingness to continue participation in the project.

REFERENCES

- Andrzejczak, J., Kozłowicz, W., Szrajber, R., & Wojciechowski, A. (2021). *Factors Affecting the Sense of Scale in Immersive, Realistic Virtual Reality Space*. In International Conference on Computational Science (pp. 3-16). Springer, Cham.
- Bangor, A., Kortum, P., & Miller, J. (2009). Determining what individual SUS scores mean: Adding an adjective rating scale. *Journal of usability studies*, 4(3), 114-123.
- Banville, F., et al. (2017). *Using virtual reality to assess the elderly: the impact of human-computer interfaces on cognition*. In: Human Interface and the Management of Information: Supporting Learning, Decision-Making and Collaboration.
- Benoit, M., et al. (2015) Is it possible to use highly realistic virtual reality in the elderly? A feasibility study with image-based rendering. *Neuropsychiatric disease and treatment*, 11, 557-63.
- Berkowitz, J. P., & Casali, S. P. (1990, October). *Influence of age on the ability to hear telephone ringers of different spectral content*. In Proceedings of the Human Factors Society Annual Meeting (Vol. 34, No. 2, pp. 132-136). Sage CA: Los Angeles, CA: SAGE Publications.
- Brooke, J. (1986). *SUS: a "quick and dirty" usability scale*. In P. W. Jordan; B. Thomas; B. A. Weerdmeester; A. L. McClelland (eds.). Usability Evaluation in Industry. London: Taylor and Francis.
- Calabro, RS. (2017). The role of virtual reality in improving motor performance as revealed by EEG: a randomized clinical trial. *Journal of Neuroengineering and Rehabilitation*, 14(1), 53.
- Cerella, J. (1985). Age-related decline in extrafoveal letter perception. *Journal of Gerontology*, 40(6), 727-736.
- Cobb, S., Ramsey, NS., Wilson, RA.. (1999). Virtual reality-induced symptoms and effects (VRISE). *Presence: Teleoper Virtual Environ*, 8: 169-186.
- Coyle, H., Traynor, V., & Solowij, N. (2015). Computerized and Virtual Reality Cognitive Training for Individuals at High Risk of Cognitive Decline: Systematic Review of the Literature. *The American Journal of Geriatric Psychiatry*, 23(4), 335–359.
- de Bruin, E. D., Schoene, D., Pichierri, G., & Smith, S. T. (2010). Use of virtual reality technique for the training of motor control in the elderly: Some theoretical considerations. *Zeitschrift Für Gerontologie Und Geriatrie*, 43(4), 229–234.

- Doniger, G. M., et al.. (2018). Virtual reality-based cognitive-motor training for middle-aged adults at Alzheimer's disease risk: a randomized controlled trial. *Alzheimer's & Dementia: Translational Research & Clinical Interventions*, 4: 118-129.
- Faria, A.N., Andrade, A., Soares, L., Badia, S.B.. (2016). Benefits of virtual reality-based cognitive rehabilitation through stimulated activities of daily living: a randomized controlled trial with stroke patients. *Journal of neuroengineering and rehabilitation*, 13(1): 96.
- Fisk, A. D., Czaja, S. J., Rogers, W. A., Charness, N., & Sharit, J. (2020). *Designing for older adults: Principles and creative human factors approaches*. CRC press.
- Freemont, A.J., Hoyland, J.A. (2020). Morphology, mechanisms and pathology of musculoskeletal aging. *The Journal of Pathology*, 211(2), 252-259.
- Gamito, P., et al. (2020). Virtual reality-based cognitive stimulation to improve cognitive functioning in community elderly: a controlled study. *Cyberpsychology, behavior and social networking*, 23(3), 150-156.
- Gamito, P., Oliveira, J., Alves, C., Santos, N., Coelho, C., & Brito, R. (2020). Virtual Reality-Based Cognitive Stimulation to Improve Cognitive Functioning in Community Elderly: A Controlled Study. *Cyberpsychology, Behavior, and Social Networking*, 23(3), 150–156. <https://doi.org/10.1089/cyber.2019.0271>
- Glisky, E. L. (2007). *Changes in Cognitive Function in Human Aging*. In D. R. Riddle (Ed.), *Brain Aging: Models, Methods, and Mechanisms*. CRC Press/Taylor & Francis. <http://www.ncbi.nlm.nih.gov/books/NBK3885/>
- Grady, C. L. (2008). Cognitive Neuroscience of Aging. *Annals of the New York Academy of Sciences*, 1124(1), 127–144. <https://doi.org/10.1196/annals.1440.009>
- Harada, C. N., Natelson Love, M. C., & Triebel, K. L. (2013). Normal Cognitive Aging. *Clinics in Geriatric Medicine*, 29(4), 737–752. <https://doi.org/10.1016/j.cger.2013.07.002>
- Hunter, SK., Pereira, HM., Keenan KG. (2016) The aging neuromuscular system and motor performance. *Journal of Applied Psychology*, 121(4), 982-995.
- Huygelier, H. et al. (2019). Acceptance of immersive head-mounted virtual reality in older adults. *Scientific Reports*, 9(1), 1-12.
- Knnan, L., Vora, J., Bhatt, T., Hughes, S.. (2019). Cognitive-motor exergaming for reducing fall risk in people with chronic stroke: a randomized controlled trial. *NeuroRehabilitation*, 44(4), 493-510.
- Kosnik, W., Winslow, L., Kline, D., Rasinski, K., & Sekuler, R. (1988). Visual changes in daily life throughout adulthood. *Journal of gerontology*, 43(3), P63-P70.
- Kueider, A. M., Parisi, J. M., Gross, A. L., & Rebok, G. W. (2012). Computerized Cognitive Training with Older Adults: A Systematic Review. *PLoS ONE*, 7(7), e40588. <https://doi.org/10.1371/journal.pone.0040588>
- Laugwitz, B., Schrepp, M. & Held, T. (2008). *Construction and evaluation of a user experience questionnaire*. In: Holzinger, A. (Ed.): USAB 2008, LNCS 5298, pp. 63-76.
- Lee, MM., Lee, KJ., Song, CH. (2018). Game-Based Virtual Reality Canoe Paddling Training to Improve Postural Balance and Upper Extremity Function: A Preliminary Randomized Controlled Study of 30 Patients with Subacute Stroke. *Medical Science Monitor*, 27(24), 2590-2598.
- Lin, C. X., Lee, C., Lally, D., & Coughlin, J. F. (2018). *Impact of Virtual Reality (VR) Experience on Older Adults' Well-Being*. *Lecture Notes in Computer Science*, 89–100.doi:10.1007/978-3-319-92037-5_8
- Molhemi, F., et al. (2020). Effects of Virtual Reality vs Conventional Balance Training on Balance and Falls in People With Multiple Sclerosis: A Randomized Controlled Trial. *Archives of Physical Medicine and Rehabilitation*, 102(2), 290-299.
- Mrakic-Spota S., et al. (2018). Effects of combined physical and cognitive virtual reality-based training on cognitive impairment and oxidative stress in MCI patients: a pilot study. *Frontiers in aging neuroscience*, 10, 282.

- Murman, D. (2015). The Impact of Age on Cognition. *Seminars in Hearing*, 36(03), 111–121. <https://doi.org/10.1055/s-0035-1555115>
- Nitrini, R., et al. (1994). Testes neuropsicológicos de aplicação simples para o diagnóstico de demência [Neuropsychological tests of simple application for diagnosing dementia]. *Archives of Neuropsychiatry*, 52(4), 457–465.
- Optale, G., Urgesi, C., Busato, V., Marin, S., Piron, L., Priftis, K., Gamberini, L., Capodieci, S., & Bordin, A. (2010). Controlling Memory Impairment in Elderly Adults Using Virtual Reality Memory Training: A Randomized Controlled Pilot Study. *Neurorehabilitation and Neural Repair*, 24(4), 348–357.
- Owsley, C., Sekuler, R., & Siemsen, D. (1983). Contrast sensitivity throughout adulthood. *Vision research*, 23(7), 689–699.
- Peng, Z., Jiang, H., Wang, X., Huang, K., Zuo, Y., Wu, X., Abdullah, A. S., & Yang, L. (2019). The Efficacy of Cognitive Training for Elderly Chinese Individuals with Mild Cognitive Impairment. *BioMed Research International*, 2019, 1–10. <https://doi.org/10.1155/2019/4347281>
- Półrola, M., & Wojciechowski, A. (2012). Real-time hand pose estimation using classifiers. In *International Conference on Computer Vision and Graphics* (pp. 573–580). Springer, Berlin, Heidelberg.
- Stöckel, T., Wunsch, K., Hughes, C.M.L. (2017). Age-Related Decline in Anticipatory Motor Planning and Its Relation to Cognitive and Motor Skill Proficiency. *Frontiers in aging Neuroscience*, 4(9), 283.
- Syed-Abdul, S., et al. (2020). Virtual reality among the elderly: a usefulness and acceptance study from Taiwan. (2020). *BMC Geriatrics*, 19(1), 223.
- Tuena, C., et al. (2020). Usability issues of clinical and research applications of virtual reality in older people: a systematic review. *Frontiers in Human Neuroscience*, 14, 93.
- United Nations Department of Economic and Social Affairs, Population Division (2020). World Population Aging 2020 Highlights: Living arrangements of older persons (ST/ESA/SER.A/451).
- Wojciechowski, A., Wiśniewska, A., Pyszora, A., Liberacka-Dwojak, M., & Juszczak, K. (2021). Virtual reality immersive environments for motor and cognitive training of elderly people – a scoping review. *Human Technology*, 17(2), 145–163.
- Wojciechowski, A., & Fornalczyk, K. (2014). Exponentially smoothed interactive gaze tracking method. In *International Conference on Computer Vision and Graphics* (pp. 645–652). Springer, Cham.
- Yamada, K., Healey, R., Amiel, D., Lotz, M., Coutts, R. (2002). Subchondral bone of the human knee joint in aging and osteoarthritis. *Osteoarthritis Cartilage*, 10(5), 360–369.
- Zajac-Lamparska, L., Wiłkość-Dębczyńska, M., Wojciechowski, A., Podhorecka, M., Polak-Szabela, A., Warchoń, Ł., ... & Izdebski, P. (2019). Effects of virtual reality-based cognitive training in older adults living without and with mild dementia: a pretest–posttest design pilot study. *BMC research notes*, 12(1), 1–8.

Authors' Note

This research was carried out as a part of project no. POIR.01.01.01-00-0951/19, entitled: "Grydsen – innovative psychological therapeutic methods for aged people with the use of VR technology", co-financed by the National Center for Research and Development in Poland.

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