Micro-moment-based Interventions for a Personalized Support of Healthy and Sustainable Ageing at Work: Development and Application of a Context-sensitive Recommendation Framework

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Abstract: The paper outlines the sustAGE system, a smart solution that builds upon strategic technology trends, such as Internet-of-Things, machine learning and recommender systems, to support sustainable work environments and increase wellness at work and well-being with a focus on the ageing workforce. Acknowledging the interrelation of the work and private arrays for healthy ageing, the developed solution utilizes a recommendation-based approach providing personalized warnings and preventive recommendations regarding occupational risks, as well as personalized cognitive and physical training activities for the off-work context with the overall goal of maintaining Work Ability and enabling sustainable work. The piloting of the proposed solution in two critical industrial domains provides promising results towards the use of personalized recommendation-based interventions for the working context and beyond for improving workers' occupational safety and health, performance and general well-being.

1 INTRODUCTION

As the overall population in the EU is getting older, the proportion of relatively older employees in all occupational sections is also increasing. The combination of this fact and the decision of most EU member states to increase the retirement age limits to at least 65 to 67 introduces specific challenges in terms of enabling factors for sustainable work (Belin et al., 2016).

Ensuring sustainable work is a multi-faceted goal and includes the common and combined consideration of work-related and general contributing factors. In terms of Occupational Safety and Health (OSH) and in accordance with the European legal framework, the notion of sustainable work considers good working conditions and the control of all risks for physical and mental health and across the entire occupational lifespan (Belin et al., 2016). In addition, the needs of vulnerable occupational groups, and the (age-) appropriate design of working conditions and respective interventions in order to meet these needs, is also concomitant to the definition of sustainable work (Belin et al., 2016). Consequently, a specific focus should be given to specific risks and challenges for OSH for the occupational group of older workers (50+).

Another concept that points out the mutual influence of work and general health and well-being for sustainable work and sustainable ageing is Work Ability (WA). WA defines the balanced interplay between occupational demands and the (subjectively perceived) ability of individuals to effectively cope with these demands (Ilmarinen & Ilmarinen, 2015). Its development and maintenance depend on several core, individual as well as contextual, work-related factors that are tightly interlinked: 1) health and functional capabilities; 2) competence/expertise; 3) values, attitudes and motivation towards work; and 4) job/task characteristics. Ilmarinen & Ilmarinen (2015) expand the boundaries of the working context

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by including private aspects, such as social environment as well as overall physical and mental well-being that demonstrate a mutual interdependence with work-related factors for WA.

WA remains generally at a high level between the ages of 20 and 65, however a cross-domain, cross-gender decline as well as an increase of individual differences has been observed after 45 years (Ilmarinen, 2006; Ilmarinen & Ilmarinen, 2015). This is also in accordance with the inter-individual variance in the way changes (i.e. decline) in physical and cognitive abilities ensue with age. Furthermore, it seems that the availability and maintenance of an adequate level of personal resources, such as general well-being and health status, can moderate the effects of ageing on perceived WA. This suggests the necessity of personalized approaches that consider inter-individual variance in order to maintain and strengthen the respective work-related resources that affect WA for older (i.e. 50+) employees (Ilmarinen & Ilmarinen, 2015).

Recommender systems provide individuals with targeted, cue-based guidance for an appropriate alignment of goals and goal-promoting behaviours (Sardianos et al., 2020). In the context of targeted interventions for human factors/ergonomics and OSH practice, recommender systems can support interventions for OSH and well-being of employees by monitoring behaviour and providing targeted and systematic recommendation-based guidance for appropriate responses.

With sustAGE we propose a holistic approach for recommendation-based interventions for OSH and well-being in order to promote sustainable work and Work Ability of older employees. This in turn is expected to reduce the likelihood of older workers to leave work by considering their health state in relation to working conditions and demands.

The recommendations are the tool for gradually shaping better user profiles, for notifying or alerting users with respect to OSH risks and recommend appropriate counter actions, and for motivating them to engage in activities that promote physical and psychosocial well-being. In order to strengthen the effectiveness of these recommendation-based interventions, sustAGE introduces a contextual aspect for the delivery of recommendations, which relates mostly to the appropriate timing of delivery, but implicitly considers the general conditions within which a recommendation is issued. This is implemented through the concept of Micro-moments (MiMos). MiMos are cues of special interest to the daily routine of each worker. sustAGE uses them to trigger MiMo-relevant recommendations.

The recommendation-based interventions incorporated in sustAGE are based on a respective conceptual framework and a focused consideration of age-specific risks and challenges for OSH and well-being and are being currently piloted in two industrial domains: manufacturing industry and maritime logistics/port operations.

In the following Section 2, we shortly outline the conceptual framework laying at the core of sustAGE and describe the specification of recommendation-based OSH and well-being interventions for the purpose of meeting the needs of two pilot occupational environments. Section 3 discusses the practical aspect of the actual implementation of the framework in two working setups, as well as for the off-work context. Section 4, illustrates some first results concerning the acceptance of the proposed intervention from the workers that participated in the pilots, the impact that it had on them and the perceived subjective workload when using sustAGE. Finally, Section 5 summarizes our findings and provides an outlook on the next steps of this work.

2 SETTING THE STAGE: AGE, OSH AND WELL-BEING, AND DOMAIN-SPECIFIC NEEDS FOR INTERVENTIONS

The design of sustAGE is relying on the development of a generic framework for recommendation-based interventions that outlines the most salient risks and challenges for OSH and well-being of older employees regardless of the specific occupation domain. It constitutes the first step for deriving age-appropriate interventions for the support and improvement of OSH and general well-being of older employees in the working context and beyond.

Further on, and beyond the consideration of general definition of age-related criticality and probability of the occurrence of OSH risks, planned interventions need to take into consideration the specific characteristics and demands of tasks and occupations in different industrial domains (Belin et al., 2016). Hence, the proposed framework serves also as supporting base-line for the domain-specific definition and prioritization of interventions.

This section provides a short outline of the conceptual framework for the sustAGE interventions and provides insights for the process of substantiation of interventions for specific occupational contexts of implementation with distinguishable characteristics and needs.

2.1 A Framework for Recommendation-based Interventions for OSH and Well-being

The objective of the proposed framework is to provide guidance for the implementation of a holistic solution towards healthy aging, by jointly improving OSH and the well-being of older employees. It postulates the well-documented correspondence between work-related factors, general well-being and Work ability. It provides the basis for a definition of the most prevalent risks and challenges for OSH and well-being for older employees that will be founded on scientific evidence and promotes the idea of the tight interdependence of the work and private arrays for sustainable work and WA.

In addition, it considers the importance of individual differences in terms of ageing, OSH and general well-being for the experienced level of Work Ability and propagates the necessity of implementing personalized interventions in order to accommodate the individual needs and characteristics.

The framework points out the need to detect and to effectively manage existing risks and to prevent future risks through targeted multi-level interventions. It differentiates between three types of recommendation-based interventions that all contribute to the goal of sustainable work: those that target workplace behaviour modification; those that target structural (i.e. working conditions conditions) modification; and interventions that target improvement of general well-being. Further on, it acknowledges the interrelations and the benefits of a joint implementation of all intervention types for the purpose of sustainable work. Figure 1 illustrates the sustAGE conceptual framework.

The framework provides a rather generic model for risks and challenges of OSH and well-being that can accommodate the implementation of targeted interventions. The design of such interventions will depend on the characteristics of different occupational environments, and on the technical specifications of the sensory environment that supports user monitoring and the respective triggering of recommendation.

Finally, it emphasizes user-generated feedback with respect to the valid assessment of user status as a necessary precondition for the effectiveness and acceptance of recommendation-based interventions by the users as well as for the adjustment of the triggering indicators and the assessment of improvements of users' overall health and well-being.

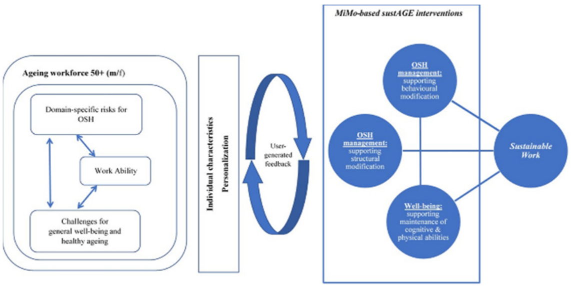

Figure 1: the sustAGE framework for OSH, well-being and sustainable work.

2.2 The sustAGE Use Cases for the Working Context

sustAGE examines two highly demanding working environments with different requirements that at the same time are crucial for Europe's economy: assembly line work in the manufacturing (automotive) industry; and maritime logistics (port/cargo operations).

Based on a thorough context-specific review of the two industrial domains of assembly line work and port operations, specific OSH risks for the use-case scenarios are outlined which can be utilized for targeted recommendation-based interventions within sustAGE.

The domain-related specification of OSH risks was based both on reviews of available literature as well as on the collection of respective empirical data from two industrial partners cooperating in the implementation and evaluation of sustAGE. The purpose of the data collection consisted in obtaining information regarding OSH risks, existing practices and potential solutions as well as cognitive, psychosocial and physical aspects of work and well-being directly from the end-users in the two occupational sites and thus tailor interventions to the specific needs in an optimal manner. The data collection took place between September and October 2019 in two respective sites.

An overall of N = 77 individuals participated in the data collection in both sites (manufacturing = 30; port operations = 47). 68 thereof were male and 9 were female. The age mean of the participants was M=53,4 (SD=4,9, Min=41; Max=66). The participation was voluntary. The test battery included 10 questionnaires and five psychometric cognitive tests available in the two languages of the sample (Italian and Greek). In addition, a short interview was conducted in order to elicit workers' perception of age-related aspects of work, and existing practices with respect to managing OSH risks, work organization and workload, work adaptations in the face of unanticipated occurrences.

2.2.1 Specification of Interventions for OSH in the Manufacturing Use Case

OSH risks for older workers in the manufacturing industry depend on task characteristics and overall working conditions. In partially automated hybrid human/machine mixed-model assembly lines, despite the technological improvements physical abilities and cognitive skills are still required in order to carry out more complex production stages not fully automated such as final assembly operations.

Workplaces and tasks in the manufacturing sector are characterized by high repetitiveness of short-cycled tasks and activities, shift work, dependence on the pace given by the line, awkward body postures, occasionally lifting heavy objects, and application of force that is associated with strain to specific body parts and muscle groups involved in the assembling/manufacturing task (mostly neck and upper extremities) (Belin et al., 2016; Boenzi et al., 2015; Guerreiro et al., 2017; Otto & Battaïa, 2017).

Continuous exposure of older workers to suboptimal working conditions can lead to discomfort, pain and health impairments due to work-related musculoskeletal disorders (MSD) and susceptibility for respective injuries resulting in health-related drop outs from work and drawbacks in productivity especially as workers' age advances (Belin et al., 2016; Guerreiro et al., 2017)

Another important aspect of OSH that is associated with MSD and working conditions is task-related fatigue. Older workers in manufacturing have reported that fatigue mainly manifests itself in strain in lower and upper extremities and the neck.

In addition, the acquired data suggest that older workers may demonstrate lower levels of WA (measured with the Work Ability Index). Figure 2 illustrates the overall WA score for the sample in the manufacturing context.

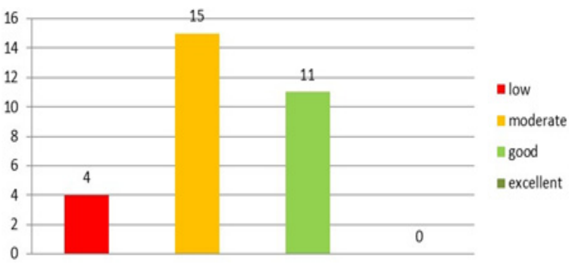

Figure 2: Work Ability overall scores-manufacturing industry.

This result can be associated with the reported low autonomy and control over the process and the amount of work when compared to older workers in port operations that may imply an imbalance in the perceived task demands and available resources (see Figure 3).

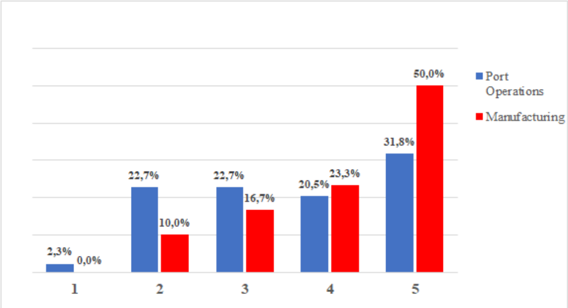

Figure 3: Relative frequencies – Influence of workers on work volume Port/manufacturing (COPSOQ Item B.3-02: "Can you influence the amount of work assigned to you?" 1=always;5=never).

OSH risks in the manufacturing context can be mitigated by providing workers with more control and decisions over the working process (e.g. break management) and with tasks that vary in cognitive demands; introducing job redesign measures for optimizing workload such as job/work station rotation and task switching; and monitoring awkward postures and physical and mental workload and fatigue in real-time and providing support (information and opportunities for micro-breaks with alternative activities) for effective mitigation.

The respective areas for interventions that target ageing manufacturing workers will have to focus on existing risks for OSH and well-being for the overall workforce and prioritize aspects that correspond highly with advanced working age in terms of work demands, available compensation capabilities, and potential consequences for safety and health.

Recommendation-based interventions should focus on the preventive management of specific OSH risks and hazards related to the repetitive execution of the same task and the associated mental and physical workload and fatigue; to the accumulated strain through awkward body postures during assembly work; the introduction of individual micro-breaks for a short-term mitigating recovery in the face of fatigue effects; and the potential utilization of the short intervals between each assembly task cycles for short physical (stretching) exercises.

Hence, respective recommendations should trigger and enable the optimization of body part stressing and mitigation of physical fatigue (that may lead to muscle strain injuries and MSD on the long run), as well as the optimization of the mental demands of consecutive and repetitive micro-tasks of medium and high complexity that may lead to mental fatigue and/or monotony effects. Apart from the preventive avoidance of injuries, discomfort and suboptimal physical and mental workload, recommendation-based interventions must also address the monitoring of environmental conditions in order to provide a proper working environment.

2.2.2 Specification of OSH Interventions for the Maritime Logistics Use Case

The port and cargo handling sector has seen the introduction of technological aids and sophisticated supporting solutions in the last decades, signalling a shift from labour-intensive towards capital-intensive operations (Turnbull, 2011). Despite the technological developments, port operations remain challenging for OSH, as port workers are still exposed to occupational hazards and discomfort factors as well as face the risk of severe occupational accidents (Antão et al., 2016). In addition, containerisation is characterized by a rather high degree of repetitiveness and reduced mental demands that may result in decreased attention during work and also overall long-term decline of cognitive abilities due to lack of challenging work-conditions and the respective work-related resources.

The respective areas for interventions that target older port workers will have to focus on existing risks for OSH and well-being for the overall workforce and prioritize aspects that correspond highly with advanced working age in terms of work demands, available compensation capabilities, and potential consequences for safety and health.

Recommendation-based interventions that focus on OSH and the well-being of older port workers should focus on the preventive management of specific OSH risks and hazards of the working set of cargo handling. In addition, different occupational groups are involved in port operations that face different risks and challenges for OSH due to the specific nature of the respective tasks, special consideration should be taken with respect to the group-related needs for implementing context-appropriate recommendations. The current recommendation system focuses on the two most significant occupational groups for port operations involving containerized cargo, crane operators (COs) and dockworkers (DWs), as these groups have been found to experience the most OSH challenges during cargo handling at the port (Walters et al., 2020).

Interventions addressing DWs should target the optimization of heavy physical workload and fatigue (that may lead to muscle strain injuries and MSD). The acquired data for the port environment confirms this issue as dock workers have reported that fatigue corresponds with back aches, as well as musculoskeletal discomfort and pain in upper and lower extremities.

In addition, as port operations take place in the open, workers are exposed to environmental conditions such as high or low temperatures. The effects of environmental conditions (especially heat stress) should also be targeted as heat stress is associated with cardiovascular impairments which can be crucial for older workers. Although other environmental conditions (such as noise and vibration) seem to be more prevalent for the manufacturing context, these should also be monitored and, if feasible, addressed in an appropriate manner. Figure 4 illustrates the workers' appraisal of the relevance of respective hazards for their working context.

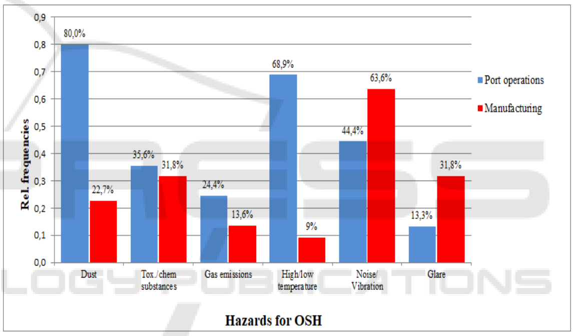

Figure 4: Relative frequencies of stated OSH hazards in port operations and manufacturing.

Safety awareness during operations must be supported in order to prevent potential accidents, and the monitoring of environmental conditions is important for avoiding workers' exposure to extreme conditions (M. Cezar-Vaz et al., 2014; M. R. Cezar-Vaz et al., 2016; Walters et al., 2020).

Respectively, interventions addressing COs should target effects of environmental conditions, work-related physical and mental strain effects associated with demands for sustained attention, responsibility, and awareness for the safety of people on the ground, musculoskeletal discomfort through continuous and constrained arm/hand postures and repetitive head and neck movements and prolonged stationary work can create preconditions for MSD and chronic fatigue as well as psycho-social negative responses such as anxiety through the increased responsibility for the safety of others (Yakub & Sidik, 2014).

2.3 Specification of Recommendations for General Well-being

In addition to the recommendations within the workplace, the system incorporates gamified cognitive training measure supports the maintaining cognitive skills that are related to work performance and general health and well-being and have been found to decline with age (e.g. memory, executive functions, processing speed) (Anguera et al., 2013; Ballesteros et al., 2014; Green & Bavelier, 2003; Strobach & Karbach, 2021). At the same time, maintaining physical fitness also corresponds with mental fitness and stress reduction for older individuals and this has been also associated with overall healthy ageing (Colcombe & Kramer, 2003; Gajewski & Falkenstein, 2015; Smith et al., 2010)

sustAGE unobtrusively and under the premise of users' consent utilizes information beyond the working context through monitoring users' patterns of overall physical activity. Based on this information, the system proposes (physical and cognitive) training activities over the day that promote wellness and support maintenance of cognitive skills and an adequate physical fitness, and also inform users over performance improvement over time in order to motivate the sustainable habituation of an overall healthy lifestyle. In addition, off work interventions address sleep quality as this issue correlates with work-related aspects such as chronic fatigue, performance detriments at work and absenteeism.

Respective recommendation-based interventions consist in reminders for practice physical and cognitive skills on a regular albeit dynamic manner (i.e. taking advantage of any idle time that users may have while at home).

In order to improve physical fitness, the system recommends off-work physical activities several times a week. In order to increase the recommendation acceptance, the system considers the location of the users two hours after they have finished work, and if they are at home, they are recommended to have 1 hour of physical activity.

Cognitive Games (CGs) provide a joyful intervention to compensate for age-related declines in cognitive functions. Six different CGs are used to provide users with the ability to exercise their cognitive skills. The system recommends the users to participate in a cognitive game challenge every second day or three times a week, but the users are also able to train with the available games any time they wish. Similar to the physical activity recommendation, the users are recommended to play CG in the afternoon when they are at home. The acceptance of the provided recommendation is automatically verified by the CG app back end which logs the hours that each user has played, his/her scores to the games and the difficulty level that is currently attributed to the given user.

With respect to sleep quality, the number of sleep hours can drastically affect the performance of the users at work. The system estimates the hours that each user sleeps every night and when they are below a specified threshold, the user is informed in the morning and asked to sleep earlier the following night. Moreover, if the average sleep hours for several consecutive days is low, the user is informed about the possibility of accumulated fatigue due to repeating poor sleep and is recommended to adjust his/her long term go-to-bed strategy.

The implicit or explicit users' response to a recommendation is recorded and employed by the system for deciding whether a new similar recommendation should be issued (or not).

3 PRACTICAL APPLICATION OF THE FRAMEWORK

In order to enable the technical implementation of the recommendation framework presented in the previous section, the following aspects have been considered: i) multiple streams from different sensors are exploited for the continuous and real-time analysis of user-centred and contextual information as these may reveal important properties of user state, actions and interactions with the environment; ii) the different modalities from sensor measurements are combined to achieve a more robust detection; iii) unobtrusive monitoring via a privacy-by-design approach is in the centre-point, exploiting a minimum setup of low-cost sensors and in parallel adopting privacy and security mechanisms in data ingestion, management and communication for improved user acceptance.

The sensor streams allow to detect low level events, which are further correlated with past user-data, and higher-level information about possible conditions or restrictions, and subsequently trigger MiMos and the respective recommendations. The system relies on a wide range of sensor feeds and devices to capture and exploit multimodal information:

Wellness Sensor. The Garmin Vivoactive-3 smartwatch is used to collect heart-rate, beat-to-beat intervals, the number of steps, and 3D accelerometer information with a dedicated smartwatch app.

Environmental Sensors. A custom solution that has been developed to enable the use of multiple third-party sensors installed in a sensor box in various places at work. They are used for capturing environmental data such as ambient temperature, relative humidity, barometric pressure, wind speed, air quality, illuminance and noise level.

Visual Sensors. Visual information is captured through a monocular camera installed on a mobile harbour crane. The camera is connected directly via GigE connection to a PC supporting all relevant processing close to the original source. This camera shares a common reference frame with the crane, as described in Lourakis et al. (2020) visual sensors are used to monitor moving containers, and extracted information is correlated with workers location data to trigger proximity alerts. In the manufacturing case passive stereo vision is exploited across each workstation to detect stressing body postures.

Speech Sensors. The human voice encapsulates linguistic and paralinguistic information, which relates to a speaker's current states, traits and well-being. Workers utterances may be captured through the microphone embedded in the Xiaomi Mi 9 smartphone used by the platform users. The smartphone plays a key role, being the primary means of interaction between the users and the system.

Positioning Sensors. Positioning information is transmitted through the smartphone multi-GNSS chipset by simultaneously tracking the signals broadcasted from all operational satellites (i. e. GPS, GLONASS, Galileo and BeiDou), providing increased robustness, reliability and spatial coverage.

3.1 Manufacturing Use Case

For detecting ***worker fatigue*** in the manufacturing case, the smartwatch is used to continuously collect heart rate (HR) and heart rate variability (HRV) data of each worker. By comparing the actual HR and HRV values with the worker's personalised "normal" values the system detects a user fatigue MiMo. Subsequently, the Recommendation Engine (RE) examines the worker's context (at work or not), the average fatigue state of the team, and the worker's sleep hours the previous day. Depending on the case, the RE either associates the fatigue with low sleep quality and notifies the worker to adjust his/her sleep schedule, or if the last night sleep time was sufficient it recommends the worker to take a micro break.

Worker safety mainly targets the repetitive actions and body postures that stress workers' body parts and may potentially lead to injuries and MSD. Taking advantage of the visual sensors, the system detects workers' postures in real-time. Postures are correlated to risk indices and if repeated for a longer period, the system immediately alerts users to change posture and perform stretching activities for compensation of musculoskeletal strain as soon as possible.

Adverse environmental conditions occasionally occur in the indoor environment of a manufacturing industry, e.g. when the A/C system is malfunctioning, when noise or dust is temporarily high. The system continuously monitors the environment to identify conditions that may cause worker's discomfort, or increase accident risks. In such cases, it notifies workers to protect themselves from the extreme conditions and their managers in order to, if possible, fix the problem.

3.2 Maritime Logistics Use Case

Worker fatigue in the port case can be detected for a single worker or a group of workers and the recommendations may differ depending on the situation. For single worker fatigue events the recommendation is for the worker to take a micro break or fix his/her sleep schedule. When fatigue events occur for multiple workers, a recommendation is sent to the foreman and the crane operator to slow down operations or grant an extra short break for recovery.

Worker safety/accident prevention: Taking advantage of the real-time users' location monitoring and the state-of-the-art computer vision that accurately tracks containers during transfer, the distance between the individual users and the moving container is continuously estimated. If this distance is below a safety threshold (i.e. users into a hazardous zone), the system immediately alerts users to move away from the container and eliminate the risk of an accident.

Adverse environmental conditions affect workers differently in the maritime logistics environment. As the dock-workers operate in the open space, the system monitors the environment to identify conditions that may cause worker's discomfort, or increase accident risks. The system blends information from the temperature, hygrometer and wind speed sensors, to compute the heat and chill index, i.e. how the current weather feels for the workers (Anderson et al., 2013). These "Feels-like" values are used to detect situations that may require the intervention of the system. In such a case, the RE retrieves the list of workers and the supervisor in their workplaces, and issues recommendations for short breaks, resting, or hydration, in case of adverse weather. Especially in the case of extremely high wind at the port, crane operators are notified to seize operations in order to minimize accident risk.

4 EVALUATION AND RESULTS

In order to evaluate the sustAGE intervention to the two domains, we engaged 23 participants (port operations =15; manufacturing = 8) who volunteered to use the system for a four weeks pilot period. The average age for the overall sample was M=54 with a SD=3,79 (port operations: M =53,5; SD =4,32; manufacturing: M = 54,8, SD= 2,53). For the evaluation of recommendation-based intervention, we distinguish three different types of criteria: i) the recommendations' acceptance, ii) the recommendations' impact and iii) the subjective impact on workers' workload.

For the acceptance of recommendations, we rely on the explicit user feedback on each recommendation, which is expressed with an "accept" or "ignore" option button that workers can press in any recommendation. For the impact we evaluate whether the recommendations have modified the workers' training habits during the pilot period, i.e. if they have performed the gamified cognitive training and if they engaged in physical activity (walking) more than before. In addition, we examine whether workers have adopted better sleep habits in order to avoid fatigue events and enhance overall well-being. Finally, we assess the users' perspective on system-induced workload and the positive or negative interference of sustAGE in the work process, we used the NASA TLX questionnaire that captures the subjective task-related workload on six different scales: mental demands, physical demands, temporal demands, quality of performance, effort and frustration.

4.1 Maritime Logistics/Port Operations

The overall recommendation acceptance in the maritime logistics scenario is higher, reaching 88% (Figure 5Figure 5). The acceptance breakdown to different recommendation types, shows that there is one recommendation (i.e. *R_heart_help*: ask if help is needed) that collects the majority of user rejections. This recommendation is either based on a misconception of the recommendation message by the workers or by an incorrect setup of the high heart rate levels, which are probably set lower than they have to be, resulting in oversensitivity for assistance requests (false-positives). If we leave this recommendation aside, the overall acceptance rate for all other types rises to 95.5%.

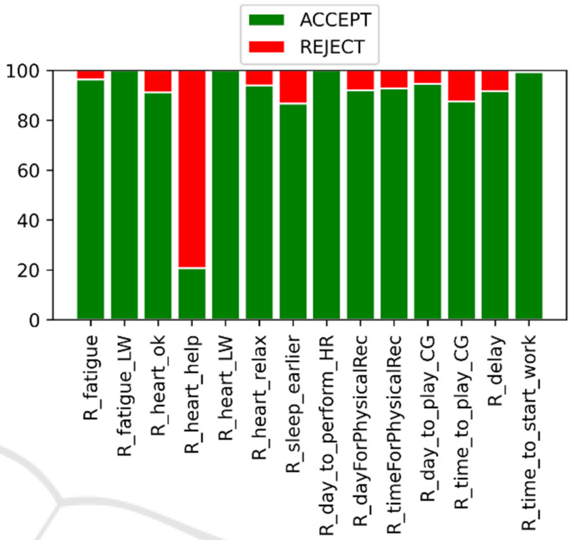

Figure 5: Recommendations' acceptance rates.

The recommendations have a direct impact on the amount of training (physical and cognitive) that the workers performed during the pilot. More specifically the average daily number of steps of dock workers increased by 700 steps within one month (a 25% increase in relation to the average number of steps in the first week). The average number of completed cognitive game-based cognitive training sessions, and the respective average high score gradually increased during the study.

Finally, the NASA TLX results have shown only one statistically significant difference with respect to the use of the recommender system. More precisely, a main effect of the system's use on quality of task performance for both groups (crane operators and dock workers) has been observed ($F(1,14) = 6,089$, $p=.027$), something that indicates that the system may have had a positive impact in the respective aspect. However, this issue needs further elaboration in order to specify the perceived benefits for performance stated by the users. With respect to the rest of the workload scales, it seems that the system does neither positively nor negatively affect workload. Considering the short phase of the evaluation and the novelty of the recommender system for the port workers, this point can be viewed in a positive manner, as working with sustAGE was not perceived as obtrusive or negatively affecting the work process.

4.2 Manufacturing

The first results on recommendations' acceptance from the manufacturing domain pilot demonstrate that the recommendations are well accepted with an overall acceptance rate of 75%. The analysis per recommendation type shows that the majority of heart rate and fatigue related recommendations have been accepted (both by shift managers and line workers), with a cumulative acceptance rate over 90%. Some technical issues related to a geofencing mechanism that detects when a worker is at work, led to the issuing of false recommendations concerning the arrival at work.

Figure 6: Average daily number of steps for the manufacturing pilot.

We also had a high ratio of rejected recommendations for performing physical training (aerobic activity/walking) after work. This is mainly because many users may draw a clear line between work and their personal life and private time. Therefore, although they accept the use of the sustAGE system in the working context, they apparently prefer to "decouple" from it in the afternoon when they are out of work and thus they seem to be rather unwilling to follow the respective recommendations, even if these can be beneficial for the overall well-being.

Accordingly, the amount of physical activity has shown a decreasing trend in this case. However, we can see that workers in general perform more steps than the shift managers and both walk more at workdays than during weekends. The main reason was that after the first week the users were occasionally taking off smartwatches in the afternoon hours, therefore the number of steps performed for the rest of the day couldn't be counted. This behaviour became a standard practice for many users by the end of the study, which is interpreted as an overall decline in the average number of steps (Figure 6).

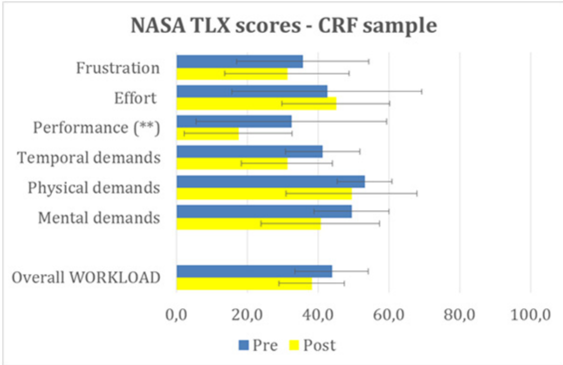

Figure 7: The perceived workload before and after the pilot execution (Performance dimension: inverted scores).

Concerning the perceived system-related impact on workload, the NASA TLX index for the manufacturing case slightly decreases from 43,8 (pre-evaluation) to 38,1 (post-evaluation) (Figure 7)
The difference between the overall workload scores is not significant before and after using the sustAGE system, so we can also infer that, similarly to port operations, sustAGE does not pose an additional impediment to work process or negatively affects the perceived workload for users in the manufacturing use case. Considering the additional technical burden that a new system can bring to the workers, the observed slight decrease in the perceived workload is a positive indication for a beneficial effect of sustAGE for supporting the working process.

Also similarly to the port environment, workers in the manufacturing context have reported better performance when using sustAGE, although the difference is marginally non-significant ($F(1,7) = 4{,}065$, $p = .084$ at a CI = 95%). Moreover, this result becomes statistically significant if the Confidence Interval is set to 90% (see figure 7). Considering the small sample size, this result indicates a clear tendency towards an increased performance quality when supported by sustAGE. Again, this issue needs further elaboration in order to specify the perceived benefits for performance stated by the users.

5 CONCLUSIONS AND OUTLOOK

The initial results that we have from the two pilot studies are promising. They show that the proposed recommendation-based intervention can be beneficial for the workers and implicitly for their employers, given that all the participants adopt the proposed framework and the changes that it brings to their routine. A more extended pilot in both cases, that is scheduled as a next step of our work, will allow us to implement the lessons learned from the first two pilot studies and further improve the results of our intervention.

More specifically, an increased number of MiMos recognized by the system produced a high number of recommendations, which in general were accepted positively by users. However, we had an indication that the number of recommendations should be slightly reduced, focusing mainly on those that are absolutely necessary to improve safety, health and productivity of employees, and sporadically addressing secondary aspects.

The difference between the perceived workload aspects of the working task with and without the use of sustAGE and the respective work-related recommendations was found to be not significant. This means that the system did not negatively affect the perceived workload especially considering some technical issues with regard to the loss of connection and the recommendations' delivery.

The sustAGE recommendations framework and its supporting ecosystem with the sensors, the processing modules, and the delivery and feedback mechanisms will allow to maximise the impact of the intervention. Moreover, it will provide ageing workers with a solution that empowers them to keep their competencies, skills and fitness at a high level and remain healthy and active in the workforce throughout the foreseen time-span until retirement (but also after retirement), setting the preconditions for and supporting sustainable work and overall healthy ageing.

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