Lived Experiences of Mental Workload in Everyday Life

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ABSTRACT

We can now buy consumer brain-computer interface devices to help us meditate and focus, but what are we aiming to achieve? Mental workload (MWL) is an established concept, and as a form of personal data could be useful for making positive life changes. However, MWL is typically only studied for isolated tasks to avoid overload and underload. We investigated lived experiences of MWL, aiming to understand how tracking such data could implicate our everyday lives. 19 participants, that had previously experienced tracking their mental workload, took part in interviews and an Interpretive Phenomenological Analysis identified four superordinate themes. Results point towards mixed and changing perceptions of MWL and the importance of fluctuating between MWL levels in daily life in terms of performances, perceptions, and wellbeing. These findings are captured in an apparent Cycle, which outside factors can disrupt, and we discuss these cycles in terms of personal informatics and work performance.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **HCI theory, concepts and models**.

1 INTRODUCTION

We know a lot about our physical activity - managing health and safety at work, and measuring physical activity for fitness. We know comparatively little, however, about managing and optimising our mental activity over a long term period, such as a day, week, or month. The not-unexpected proliferation of commercialised neurotechnology, to help us either focus[1] and/or meditate[2], shows that people want to turn their mental activity into personal informatics [52], as we do with physical activity tracking [13]. This is especially the case as more forms of work turn towards cognitively challenging, rather than physically challenging [55], and for our ageing society where clinicians recommend against cognitively

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[1]e.g. Neurosity - https://neurosity.co
[2]e.g. Muse2 - https://choosemuse.com/muse-2/

sedentary behaviour [36]. However, there is a need to investigate what cognitive data would be useful for neurotechnology users to track longitudinally that enables goal setting for the optimisation of certain aspects of our lives. For some forms of personal informatics, users have found the data collected to not be useful for meaningful insights, which is a barrier to technology adoption [38] and continued use [20].

Mental workload (MWL) is a concept that is as relevant now as ever [23] as it is an underlying factor for performance at work [66] and for many life tasks [19, 55]. Tracking MWL in our lives could be a valuable form of data, which could help to optimise performances and aspects of our lives. Indeed, much research seeks to objectively measure MWL in the real-world [2, 46, 66], but this is generally aimed towards avoiding exceeding MWL capacity in safety-critical situations [66]. Hence there is a lack of understanding about MWL outside of isolated-task work environments, in terms of how it affects our day-to-day lives.

In this paper, we investigated lived experiences of mental workload using a holistic and person-centred interview approach and aimed to understand: RQ1) How are experiences of MWL perceived (positively and/or negatively)? RQ2) What impact does MWL have on our lives and work, and vice versa? RQ3) What goals should we be setting in terms of MWL? We ask these questions with the intention of developing insights into how future consumer neurotechnology could track meaningful cognitive data that helps people set goals, and into a deepened understanding of how work performance, in terms of MWL, is related to daily experiences.

The study used Interpretive Phenomenological Analysis (IPA) to reveal four interrelated superordinate themes which describe both the factors affecting people's experiences of MWL, and the strategies people have for managing and optimising it in their lives. Our primary contribution outlines how people should aim for a MWL Cycle of fluctuations in daily life in order to facilitate positive performances, perceptions, and wellbeing.

2 RELATED WORK

2.1 Mental Workload

Mental workload lacks a universal definition, but it is generally agreed to be comprised of a) the demands of the task and b) the experience of responding to the task [55], in terms of c) the resources available to meet the demands [66]. Megaw and Sharples describe how MWL can be increased until a point where task performance will suddenly drop [56], as when the demands of the task exceed the person's resources available, performance errors can happen [34]. These maximum resources vary by both individual (e.g. cognitive span) and situational (e.g. alertness, vigilance, and fatigue) factors [56]. When there is too little stimulation, the available resources are

either focused outside of the task or reduced because of underuse [67]. MWL, therefore, is predominantly researched within human factors and neuroergonomics, where a primary focus is preventing 'crashes' in performance in largely safety critical tasks. If for example a driver, pilot, signaller, or air traffic controller becomes overloaded or underloaded when interracting with a system, mistakes and serious incidents can happen [66]. Hence, typically such work tasks and even shift patterns are designed to remain within employee's capabilities [55]. MWL can be considered closely related to the Mental Effort [28] required to achieve a task and similar concepts in other disciplines, such as Cognitive Load Theory [61].

The experience of responding to a task makes up half of the identified components in MWL, but research largely only considers the resources available without considering to whom those resources belong. We believe that approaching MWL from a more holistic perspective should involve understanding people's perceptions of the concept itself. Individual perceptions of MWL might affect how people respond to the use of their resources which may affect their performance. Understanding MWL as a person-centred, whole entity could implicate how people approach their MWL lives as a form of personal informatics [38]. It could also implicate further understanding of overload and underload at work in terms of the personal factors that contribute to these given states. Therefore, where most MWL research focuses on the avoidance of overload and underload to improve performance at work [66], we are focusing on the MWL levels in between these extremes. For these reasons, it seems important to investigate the effects of MWL levels in our lives, in terms of, for example, our daily performances, cognition, behaviour, or wellbeing (RQ2), and thus what we should aim for (RQ3).

2.2 Neuroergonomics and HCI

Neuroergonomics is the study of the human brain in relation to performance at work and in everyday settings [48]. A research aim in neuroergonomics is to improve safety and performance in the real world [46] and an area of research within this is the objective measurement of MWL using brain imaging methods [47, 49]. An exciting, optimistic, and realistic prospect is that we are getting closer to being able to continuously track MWL levels in the real-world using brain imaging methods [2, 46, 66]. Electroencephalography (EEG) and functional Near-Infrared Spectroscopy (fNIRS) are neuroimaging methods which have shown suitability for real-world measurements, as technical developments mean they can now operate portably and are relatively robust against movement artefacts [51]. fNIRS in particular is gaining momentum and showing promise [29]. For example, fNIRS has been used to detect different MWL levels in realistic air traffic controller tasks [4], driving tasks [25], remotely operated vehicle tasks [14], and to help air traffic controllers to recognise their own levels of MWL [40]. Research is at an early stage, but studies aiming to objectively measure MWL in real-world tasks using brain imaging methods are increasing sharply and are considered to be part of the next generation of MWL research that may allow the continuous and non-intrusive quantification of MWL in real-world environments [66]. If (or when)

this is achieved, it is hoped that MWL can be controlled such that safety and performance at work will be improved [56, 66].

In the HCI field, research has aimed to use MWL levels as a way of predicting good moments for interruptions in work [32], where Salvucci et al showed that participants are more likely to switch to a secondary task during moments of low MWL [54]. Iqbal et al studied changes in MWL at a micro-level within tasks, noting changes in MWL at subtask change points for example [31]. Similarly, Midha et al investigated whether fNIRS measures could differentiate between MWL levels of different difficulties of reading and writing tasks [42]. However, the aim of our research relates to how tracking mental workload data may be a useful tool in our daily lives by aiming to understand the role MWL plays in our lives outside of work.

It should be noted that, as sensors are being developed to detect MWL levels from physiological data (including other non-brain related approaches, e.g. Fridman et al [26]), subjective tools are another method used to measure MWL in tasks. However, these do not offer the potential for continuous and non-intrusive MWL measurements as they require input from the subject [56]; subjective ratings therefore need to be given at task intervals, which may cause disruption to the task, or given retrospectively, which may be prone to inaccuracies. Therefore, physiological measures enable accurate and continuous monitoring of MWL in real-world environments; brain imaging methods are arguably offer the most promise for this. That being said, NASA-TLX [28] is perhaps the most known subjective post-task measure that captures both physical and mental aspects of workload. Otherwise, ISA [37] and IWA [50] are used in industry contexts for mid-task subjective reporting of MWL levels.

Indeed, subjectively self-tracking symptoms and behaviours is frequently practiced in the health and wellbeing space by patients with chronic conditions [5, 6, 10, 44]. This has been shown to increase patients' reflection, understanding of their condition, and support management behaviours [44]. However, manual self-tracking is inconvenient to complete, highly subjective, and often completed inconsistently [6]; the burden of self-tracking prevents people from adopting long-term self-tracking practices [21]. Thus, automatic monitoring devices are increasingly being researched and developed (such as wearable sensors), with the aim of lessening the burden of self-tracking whilst retaining its benefits [10]. This emphasises how people want to understand themselves better, and benefit from doing so; advances in technology, which are making substantial progress in the monitoring of certain cognitive and physical states, have the potential to enable long-term and continuous tracking.

2.3 Brain-Computer Interfaces

Brain-computer interfaces (BCIs) refer to the recording of brain signals, where features are extracted and converted into artificial outputs, such as messages of communication from people with severe motor disabilities [2]. The field has expanded, and now a large amount of research measures brain activity in healthy subjects. In the area of wellbeing, BCI devices that measure affective states (mood and emotion) can be used to modify human-computer interaction [60]. Daly et al. [12] developed a BCI system that detected a user's emotional state and played targeted music to control their

emotion, e.g. making the user feel calmer or happier. Other research has aimed to use BCIs to help people regulate their mood by providing visual cognitive feedback [27]. Further, a large BCI research area focuses on passively tracking cognitive activity in healthy subjects, known as passive BCI (pBCI) [2]. Progress in the pBCI field has been substantial, and it is believed that the technology is not far away from becoming freely available to consumers [3]. Examples of current neurotechnology that are commercially available include devices that provide real-time feedback on brain activity to help users meditate, [3] devices that personalise a user's surroundings based brain activity measurements to achieve and maintain focus, [4] or devices that translate brain activity into actions whilst gaming. [5] Whilst currently at an early stage, the neurotechnology market is growing considerably in quantity and investment [35], suggesting a relatively imminent bloom in pBCI neurotechnology.

Due to being at an early stage of development, consumer neurotechnology currently faces several issues. For example, neurotechnology outside of the medical field is largely legally unregulated [63], meaning users are not guaranteed that the data is valid and representative of true cognitive function [15, 30], and current cognitive activity measures need to be worn fairly obviously on the head, which may not currently be suitable for longitudinal use due to device discomfort and social aspects. However, it is likely that future technology will have the ability to track cognition from more commonly wearable sensors [1], such as the wrist or more subtly and comfortably from the head. The present research aims to investigate the type of data that could provide meaningful insights to users for when neurotechnology has advanced enough to capture it.

Similarly to the neuroergonomics field, measuring MWL to provide feedback to users is an aim within pBCI research [2, 3] and this is speculated to be useful for improving work tasks [3], as mentioned previously. Giving people feedback during a task, however, is comparable to tracking isolated physical workouts instead of physical activity over time. This is the approach taken by currently available neurotechnology, in the sense that they aim to take brain activity measures only for the duration of a 'workout,' such as a meditation session, instead of over a period of time. Similarly to physical activity tracking that can tell you how many steps and calories you have burned over the last day, week, month, year etc, research addressing how to design feedback for a healthy lifestyle of MWL is important for the development of meaningful MWL tracking neurotechnology. Our research questions (especially RQs 2 and 3) aim to understand how people approach MWL in their lives, and what goals they should be setting in that regard.

2.4 Personal Cognitive Informatics

With the world becoming less physical and more technology focused, MWL is as relevant now as ever as a concept to be considered in our daily lives [23]. Our work-life balance is becoming ever more blurred, we frequently perform cognitively based tasks outside of the workplace [19], we strive to optimise our efficiency and performance at work, and we seek to lead healthy and happy lives [11].

Research has shown that high levels of MWL at work play a role in accidents at home [17], and the impact of the weekend can affect accidents at work [16]. Similarly, demands for mental effort in our home lives can lead to poor performance at work [33]. We do not have a clear picture, however, of how people would try to manage MWL in these different cases if they could measure their brain data as a form of personal informatics, or how workplaces might adapt to understanding MWL from a broader perspective. Hence, investigating lived experiences of MWL could provide understanding of what should be aimed for. Miles et al. [43] highlight the importance of understanding people's lived experiences, metaphorically comparing it to an onion, where each layer reveals a different and rich meaning.

Personal informatics [21, 38] is grounded in quantifying aspects of our lives through tracking and using that data to optimise or change behaviours [52, 53]. With the continuous measurement of MWL a real possibility on the horizon, MWL could be useful as a form of personal informatics, like a Fitbit for the brain [65]. Here we try to draw useful (although not infallible) parallels with physical activity tracking. The new consumer BCI devices take brain measurements comparable to gyroscopic data in phones and watches. Their interpretation of this data into physical activity e.g. steps or swimming strokes, would be comparable to their ability to make inferences about relaxation or focused attention, or indeed MWL levels. Beyond this, our work focuses on what people would want to know, or indeed try to achieve, if they had this form of personal informatics, as a parallel to trying to reach 10,000 steps a day, or train for improving fitness. Though as MWL is not a tangible concept like physical activity data, people are individual in the way that MWL should be approached in their lives, and therefore this research is approached holistically.

3 STUDY DESIGN

To answer our research questions about everyday MWL, we performed a qualitative interview study and used an Interpretive Phenomenological Analysis (IPA) approach. IPA is a qualitative approach and the aim of IPA is to understand participants' lived experiences, exploring one's personal perceptions or accounts of an object or event [58]. It is modelled on people as self-reflective and self-interpretative beings who reflect on their experiences and try to interpret them [58]. In IPA, each participant's data is considered in depth to enable an idiographic approach before more general claims about the data are made [58]. Additionally, the use of IPA is especially suitable for topics that are contextual, subjective, and relatively under-studied [57]. IPA was favoured over thematic analysis (TA) in this study because TA focuses on patterns across the data set; it does not provide a sense of contradictions within individual accounts, and the voices of individual participants can get lost [9]. Indeed, IPA does consider data patterns, but is also concerned with individual experiences [58], which is what we are exploring in this study (lived experiences of MWL).

3.1 Participants

19 purposive participants took part in the study, recruited by opportunity sampling. Participants responded to advertisements put out through email groups and social media channels. To be included in the study, participants were required to (a) complete office work

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as part of their jobs, (b) be Android users, and (c) have no clinical history of anxiety or depression. Out of the 19 participants, 9 were based in academia and 10 were industry workers (see Table 1). Ages ranged between 21 and 45. Office workers were chosen as a sample considered representative of our wider focus on tracking cognitive activity in daily life as a form of personal informatics; work tasks in this sample were considered to be primarily cognitively based as opposed to shop or factory style work which may e.g. include more influence from physical workload and fatigue. Ethical approval was granted for the study [CS-2019-R13] and all participants provided informed consent before data collection began. Participants received £100 as remuneration for their interview and preparation week (see below).

3.2 Procedure

To enable a rich and insightful discussion about what MWL meant to each participant, prior to the current study, all participants underwent a week of a type of MWL tracking, where they logged their subjective MWL ratings at regular intervals from wake until sleep based on an ISA scale (which has a MWL rating from 1-5) [37]. Prior to their week of MWL tracking, participants were provided with a document detailing the aims of the study, highlighting that we wished to develop an understanding of their MWL experiences and perceptions. The document encouraged participants to 'tune in' to their MWL levels and experiences throughout the week and to think deeply about what MWL meant to them. A brief introduction to MWL was provided, in which it was stated that no definition is universally agreed, but the MWL components were provided. It also mentioned how MWL is not the same as stress (in which the researchers have previously experienced participant confusion), and provided a few example questions from the interview. By the time of the interviews, each participant had therefore had the opportunity to think deeply about MWL before being probed about their own lived experiences of MWL.

The primary interview data for this study was collected using digitally recorded semi-structured virtual interviews. For each MWL level (high, medium, and low), participants were asked to talk about their feelings, perceptions and attitudes about MWL and the believed implications it has in their lives. Examples from participants' lives were encouraged whenever appropriate; when encouragement was needed, the interviewer used the participant's time in the week-long tracking study as a prompt, by referring to a graph of their MWL ratings throughout the week (Figure 1) and pointing out relevant sections that may help answer the questions. The semi-structured nature of the interviews meant that the researcher was guided by a set of pre-defined questions (Appendix A) but participants were probed on individual topics that they mentioned and encouraged to talk at depth. Interviews typically lasted between 1-2 hours.

3.3 Analysis

The interview data was transcribed verbatim, and the analysis followed the method outlined by Smith [58]. The lead researcher firstly familiarised themselves with the transcript. Comments were then noted in relation to first impressions and interpretations of the participant's account; different ink colours were used to indicate whether the comments were descriptive or interpretive. These notes were then translated into emergent codes. Once all emergent codes had been created, connections between them were identified and emergent themes were grouped together to materialise as initial subthemes umbrellaed under their superordinate themes. This was repeated for each participant, whilst using the themes from previous transcripts to orient the analysis. Respecting divergences as well as convergences in the data remained a priority throughout the analysis. After all transcripts had been analysed, a final set of superordinate themes and their subthemes were identified across the full set of data; the number of subthemes for each superordinate theme was reduced to only be representative of either rich or frequent data. In the results section, each participant is referred to by a number, e.g. P15 refers to participant 15.

Quality Assurance and Positionality. To ensure good qualitative research practice, guidelines by Elliott et al [18] were followed. This involved verifying the credibility of the results by all researchers checking the data and collaboratively working with the data once transcribed. In particular, pairs of researchers discussed and challenged the emerging structure of themes and how subthemes related to each other, such that they went through several stages of refinement. Final themes were also subject to a team review, where the themes and their implications were presented and questioned. The final themes and data presented here are grounded in examples from participants to illustrate each theme and descriptive data about participants is also outlined. The perspective [18] and positionality [8] of the researchers are important to consider in qualitative research, as these are factors that can influence the research process [8]. This research falls within a WEIRD[6] context [39] represented by all researchers; 18 participants were UK based - 5 UK based participants were from South America and 1 participant was from and based in India. The researchers in this study all have a level of expertise pertaining to MWL as a concept and it is reasonable to assume they have considered their own views on MWL in daily life more than the usual office worker. Further, two of the research team self-described as hyper-organised, aiming to maximise their workload at work, and equally at home managing family life. The researchers recognise that their personal interests and assumptions about the topic may naturally play a role in their approach and understanding of the research outcomes [18].

4 RESULTS

Four master themes were identified from the transcripts: 1) general perceptions of MWL, and 2) changing perceptions of MWL, which together outline the fundamental perceptions of MWL and the factors that can change these perceptions. Theme 3) the MWL Cycle, is where we present a Cycle regarding the necessity to fluctuate between MWL levels in certain patterns, and 4) the Cycle can't always be facilitated, outlines the factors that prevent these fluctuations.

4.1 General Perceptions of Mental Workload

Participants were probed about their general perceptions of low, medium, and high MWL levels. For high and low MWL, participants' perceptions were either positive or negative. Different perceptions

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[6]From their critique of HCI research: Western, Educated, Industrialized, Rich, and Democratic.

Table 1: Table showing participants by ID, along with the occupation, age, and self-identifying gender.

Participant	Occupation	Age	Identify as
P1	PhD Candidate	25	Male
P2	Regional Account Manager – Field Sales	24	Male
P3	PhD Candidate	45	Female
P4	Post-Doctoral Researcher/Teacher	32	Male
P5	Research Fellow	35	Male
P6	PhD Candidate	28	Female
P7	PhD Candidate	30	Male
P8	MSc Candidate	27	Male
P9	PhD Candidate	27	Female
P10	Commercial Finance Manager	44	Female
P11	PhD Candidate	31	Male
P12	Copywriter	33	Male
P13	Ecologist	26	Female
P14	Business Support Administrator	32	Female
P15	Software Engineer	21	Male
P16	Programme Support Officer	41	Male
P17	Software Engineer	33	Male
P18	Voluntary Deputy Services Manager	35	Female
P19	Senior Health Economics Manager	33	Male
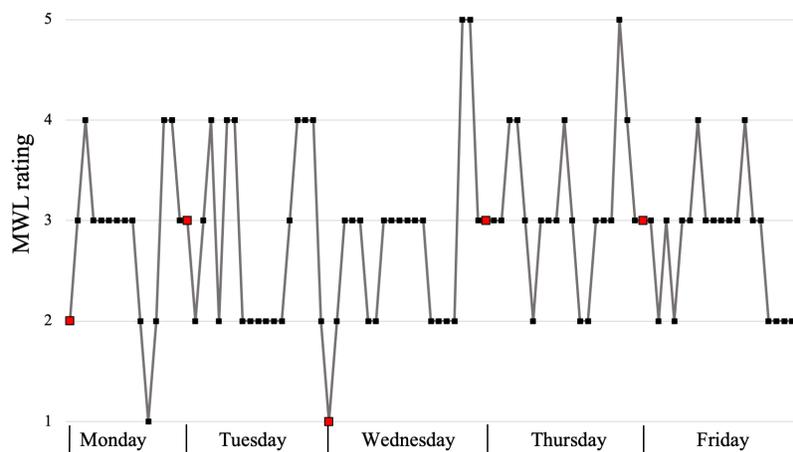
Figure 1: An example graph showing the subjective MWL ratings given by P1 which was used as a prompt during the interview (red points indicate the first rating of each day).

at the same level (for high and low) were found among participants. For medium MWL, participants' perceptions were rarely described negatively.

4.1.1 High Mental Workload. High MWL was conceptualised by participants as either a state of deep concentration, or by a state of 'busyness' in terms of managing a large quantity of tasks. Indeed, some participants, such as P19, conceptualised high MWL as having both of these dimensions: *"I would probably split it up into two where I gave high mental ratings I would say one where I was trying to do lots of different things at the same time … but then there's the other side where there's a high mental workload where you are really focused on a particular activity and generally I perform better in that instance*

like if there's a high mental workload because I can focus on one thing and really dig deep and think about it."

Alongside reflecting on what participants perceived high MWL as 'being,' several positive and negative feelings were associated with operating at this level. Many participants described feeling fulfilled during and after periods of high MWL: *"I think it's actually one of the things that in my opinion makes work a lot of times rewarding you know being able to think hard about stuff"* (P5). Similarly, P9 said *"I think when you solve things that are challenging it's like you feel comfort at the end and you feel like you did something like well and I feel relaxed after the day if I say that I had really high mental workload but I was able to overcome it."* Participants also felt enjoyment, positively stimulated, and less distracted (which

Table 2: Table showing the final superordinate and subthemes from the Interpretive Phenomenological Analysis

Superordinate Theme	Subthemes
1) General Perceptions of Mental Workload *Describing the feelings associated with different levels of mental workload*	Positives high Negatives high Positives low Negatives low Positives medium
2) Changing Perceptions of Mental Workload *Describing factors that can affect perceptions of different mental workload levels*	Pressure Enjoyment Outcome Location
3) The Mental Workload Cycle *Describing how people use, combine, and manage the levels of mental workload.*	The cycle Sustainment is an issue Each level serves a purpose
4) The Cycle Can't Always be Facilitated *Describing factors that can disrupt access of different levels*	Life factors Internal factors External factors

were each recorded as codes in the analysis) and thus it is clear that positive associations are often made with being at a high MWL level.

Significant negative feelings were also associated with being at a high MWL level. Participants often described high MWL as feeling like pressure, and could be experienced as stressful and sometimes overwhelming: *"I just feel like stressed and I know that I need to prioritise and maybe I'm struggling to prioritise at that time cause I feel like there are too many tasks that I need to look at the same time"* (P6). *"I never really long to be at a five [the highest MWL rating]. I think it feels quite out of control being at a five for any long period of time"* (P16). As a result of these negative feelings, participants may avoid operating at that level. Taken together, high MWL can be perceived at opposite ends of the spectrum in terms of positive and negative feeling associations, and this is individual to each person. As maybe to be expected, this was also true for feelings associated with being at a low MWL level.

4.1.2 Low Mental Workload. Low MWL was typically described as the feeling where one can operate on autopilot, or as a state where one feels like there is a lack of activity (whether good or bad). *"I wanna say it's just sort of like the default feeling I guess nothing interesting's really happening it's just sort of I wanna say sort of tedious"* (P15). P14 described it as when everything has been achieved for the day: *"See I think that [low MWL] counts as when you've not got anything to do so like at 10 o clock when the kids are like in their bed that's when I would say I have a low mental workload because I've not got anything else to do."*

These two conceptualisations of low MWL appear related as they are both associated with low levels of demand, and like the associations with high MWL, operating at a low MWL level was generally associated with both positive and negative feelings. Participants positively described low MWL as relaxing, enjoyable, and indeed more manageable: *"[A low MWL day] it'd be an enjoyable chilled day just recharging chilling enjoying yourself"* (P13). Perhaps more

surprisingly, some participants reported low MWL had an impact on how they view the world around them in terms of manageability: *"If I'm just bumbling along I feel like my whole life feels a bit more in order like personally and at work like it feels a bit more manageable."* (P13)

Participants also reported a considerable amount of negative feelings generally associated with being at a low MWL level, being boring at the least. *"When you're operating at a low level it becomes quite mundane. Everyday just feels a little bit the same, I suppose that's how it is"* (P16). Many participants felt unsatisfied and unproductive at a low MWL level: *"Oh my gosh I would try to fill it in with anything … just to feel like 'Ok I did something a little bit productive today'."* (P7)

Participants often reported feeling more prone to distraction when at a low MWL level: *"I have a lot of distractions and I look at my phone like too many times on the social media like Instagram, Snapchat or Facebook. Even though I know that I have no messages I'm just opening them, I see I have nothing and then I just close the apps"* (P8). This supports related research that showed people self reporting as more easily distracted were more likely to be so at low MWL [24]. As specific codes, the feelings of boredom, unproductivity, dissatisfaction, a lack of enjoyment, and distractable were negative feelings generally associated with experiencing a low MWL level.

It is worth noting that there was no consistent form of polar trend between perceptions of high MWL and perceptions of low MWL; for example, participants that generally had positive feelings associated with high MWL did not necessarily have negative feelings associated with low MWL.

4.1.3 Medium Mental Workload. Whilst high and low MWL levels were associated with both positive and negative feelings, medium MWL was overwhelmingly associated with positive feelings. Medium MWL seemed to be perceived as 'a happy medium' which counteracted the negative associations of the high and low

levels, whilst retaining in some form their positive associations: *"You're in danger in the low to procrastinate on stuff to other things because you don't feel mentally challenged and then conversely on the high you might wanna try and avoid it because of the taxation of it. I think medium's a sweet spot if that makes sense where you know that you're using a bit of mental load but you're not overdoing it"* (P19). Here Participant 19 described medium MWL as having the right balance of intensity and activity; given their earlier account of high MWL, it can be assumed that this passage applied to activities related to either quantity or mental absorption. The association of medium MWL as being the 'sweet spot' was reflected by other participants who further disclosed that the balance between low and high levels generated feelings of comfort, enjoyment, and control. E.g: *"It's comfortable it's like you are not at your high level of stress or things to do but you are not without doing anything I think it's cool to be there."* (P9)

4.2 Changing Perceptions of Mental Workload

Where the previous theme outlines underlying perceptions of MWL at each level, this theme outlines certain caveats (pressure, enjoyment, outcome, and location) that can change these perceptions.

4.2.1 Pressure. Participants reported that high MWL tasks that were associated with pressure, in the form of external pressure or time pressure, resulted in negative feelings towards the task: *"If I've got a busy workload and it's not like super intense deadlines I don't mind that it kind of makes time pass quicker, [and you've] got things to focus on but yeah if it's like I have to do everything now I don't enjoy that at all. I don't think I deal very well with stress and intense pressure so I don't think I enjoy that"* (P13). In this case, Participant 13's experience of a high MWL level is turned more stressful by the time pressure associated with the task, to the extent where a fairly positive experience of high MWL is turned into a negative one that is associated with stress and pressure. Indeed, when stress was mentioned in interviews in relation to MWL, it was typically in relation to immediate or consequential pressure.

4.2.2 Enjoyment. Whilst pressure is a reported factor that seemingly affects perceptions of high MWL, task enjoyment was described as a factor that affected the perceived feelings of all MWL levels: *"If it's something like work or whatever home task that requires a medium mental workload or if it's something like sports or playing a competitive game then it definitely feels different, probably to do with the enjoyment that's associated with it"* (P15). So enjoyment of the task or activity affected the experience of being at a medium MWL level for Participant 15. This caveat did not necessarily mean that Participant 15's medium MWL experience went from negative to positive when participating in an activity that they associated with more enjoyment, as they reported simply the change in experience between activities.

4.2.3 Outcome. Perceived experiences of different MWL levels were often found to be affected by the outcome of the task or activity, particularly as a factor associated with the negative low MWL experiences reported above. Participant 8, however, reflects on this in terms of amount of work produced from high MWL periods: *"If I'm being productive I do [enjoy high MWL] … but if I feel like I haven't advanced or progressed that much I feel stressed*

cause I feel like I'm wasting my time, I have no good results" (P8). So Participant 8's whole experience of being at a high MWL is dependent on whether they are progressing through the task(s) at a satisfying rate, and thus the outcome, or ongoing outcome, of the task is a key factor in the perception of MWL. This finding was also identified for the low and medium MWL levels.

However, it is not only personal assessment of the task output that might affect how the MWL level is perceived. Participant 1 described how the external response to the output can influence how the level is perceived: *"So I feel better in meetings when there's some kind of positive feedback of some sort … When I talk my eyes wander a lot or I look around my room cause there's not a person to look at, and when I look back, some calls I just see a bunch of blank faces staring at screens or like at their own thing, and sometimes I look back and they're smiling and nodding and I'm like, 'I'm doing alright, the point I said's valid' and those ones feel better at the same workload. So I'm trying just as hard to make a point and there's like an extra good feeling that comes from looking back and someone's smiling or nodding and like 'ok that was a good point'"* (P1). This passage indicates that not only does the internal assessment of the output affect the perception of the MWL level, but the internal assessment of the external response affects the perception of the MWL as well.

4.2.4 Location. The environment in which a low MWL level is experienced was a recurring code that affected how participants perceived being at a low MWL level: *"It feels less guilty when I'm outside work because when I'm doing work and I'm rating myself low it almost feels like it means I'm not doing much or I'm not doing enough and I think it brings about some sort of guilt which is weird because it shouldn't but it still does"* (P5). As an interesting example of reflection on this kind of data, Participant 5 describes how being at a low MWL level at work (as a Research Fellow) generates feelings of guilt which is not present when outside of work hours. They acknowledge that there is no basis for that association, but reflect on how it almost cannot be prevented in that environment.

Location was also often reported to affect the enjoyment factor, above, of being at a low MWL level: *"If it's [low MWL] at work I become apprehensive, maybe a bit irritated and I am anticipating the boredom. But if it's personal life then yeah probably quite happy [to be at a low MWL], so I'll spend the day doing the cleaning washing the pots doing some laundry watching the telly going for a walk all very low mental workload stuff but I'm quite happy to do that"* (P10). As reported in several places so far, it is evident that some people alter their priorities for low and high mental workload for different parts of their life, as well as within parts of their work; Participant 10 has negative associations of low MWL when working (as a Chartered Accountant) but reported more enjoyment of being at a low MWL level in their personal life.

4.2.5 Summary. Taking the two themes presented above together, we can reflect on the different perceptions at the same level for high and low MWL. The positive feelings high MWL was associated with included feeling: fulfilled, enjoyment, stimulated, and less distracted, whereas the negative feelings included feeling: pressured, stressed, and overwhelmed. The positive feelings associated with low MWL included feeling: relaxed, enjoyment, and manageable, and the negative feelings included feeling: bored, distracted,

unsatisfied, and unproductive. Medium MWL was only perceived positively, as a "happy medium," in terms of feeling comfort, enjoyment, and in control. These initial perceptions are subject to change, however, with the presence of caveats (pressure, enjoyment, outcome, and location) which can completely change the MWL perceived experiences.

4.3 The Mental Workload Cycle

Theme 3 presents an apparent Cycle in which fluctuations between MWL levels are important for increased wellbeing, optimal performance, and positive MWL perceptions. This is because each MWL level serves a different and important purpose to the individual, and negative consequences are likely to happen if any level is sustained for too long.

4.3.1 The Mental Workload Cycle. The Cycle describes how participants fluctuated between the different MWL levels in specific *patterns. "Whether it's low, medium, or high, you have to have variety to be the most efficient person. If I was to define a perfect day it would be a mix, so some low mental tasks, some medium mental tasks, some high mental tasks. That's kind of the days I'd probably define myself most efficient"* (P19). P19, a senior health economics manager, described fluctuating between MWL levels in terms of efficiency; they feel like it's the balance between the levels that enables an efficient self. What the passage echoes from many participants, is that they deliberately seek out fluctuations in MWL levels, often in particular patterns:

Firstly, after experiencing a high MWL level, participants would typically transition directly to a low MWL level: *"I do seek out low mental workload breaks so if I'm doing something that's going to take me a long time but is at a sustained high level, probably every couple of hours I will go and look at my emails and just reply to a few things and then come back to it"* (P10). While P10 described the fluctuations within tasks as a break, some described transitioning to longer periods of low MWL after longer periods of high MWL had been completed: *"I have a band and we sometimes record in a studio. We have to do it for the whole day because I mean it's hard to get people into the same room on the same day so we have to go there from like I dunno, 9am in the morning to 9pm or 7pm in the evening. So it's constantly high mental workload, listening and getting comments and feedback and everything … After I'm done I'm just gonna chill, just find something that really disconnects me, like reality TV or something like that."* (P7)

Next, participants actively sought out higher MWL levels when experiencing a low MWL level: *"I would seek high mental workload [when at a low MWL level] … I often have a lot to things on my to do list so I can create high mental workload by not doing things in my own mind cause they're there playing on my mind, so by doing them, A, I'll get some reinforcement out of whatever it is, but it can dial down that anxiety about not getting things done"* (P18). Similarly, Participant 1 described that they seek to raise their MWL level to seemingly anything above a low level: *"I could sit in front of the TV all day not really doing much, flicking through my phone or watching YouTube or whatever … but it doesn't feel very good... If it's in my power I'll put tasks in there to make it higher. It's the reason that I book meetings in or find new opportunities I guess... I'll put something in on purpose to stimulate myself"* (P1). Whilst Participant 1, like

many of the participants, did not specify which MWL level they would transition to from a low MWL level, it is clear that they aim to transition to a 'higher' level. Further passages described activities that are undertaken after experiencing a low MWL level, we interpret that participants did seek out medium MWL levels as well as high MWL levels after a period of low MWL: *"I do yeah most definitely [seek higher MWL levels when experiencing low MWL]. I've always been a big reader, always read a lot of books and they're not always, you know, highly cerebral or anything, they are trashy novels quite often, but just to keep the brain working I got through about 40 different books last year so I will always seek out something."* (P10)

Whilst the general consensus in theme one was that participants were more happy sustaining a medium MWL level compared to a high or low level, participants did eventually seek out either a high or low level. Interestingly, each participant had a clear preference about whether they would seek up or down from a medium MWL level. Participant 14, for example, tended to seek out a high MWL from a medium MWL level: *"I'd probably be quite happy there [at a medium MWL level] but I would probably always tend to seek for the higher workload rather than the lower one"* (P14). On the other hand, Participant 13 preferred not to transition to a high MWL level from a medium level; instead they would seek for a low level of MWL. *"I think I'm happy to stay at a medium mental workload for a relatively long period of time. I think eventually you probably would seek out low levels, I don't think I'd ever feel like I need to seek out high levels."* (P13)

From the findings in this subtheme, participants aim to fluctuate between MWL levels and this occurs in specific patterns. Specifically, from a high MWL level, participants seek out a transition to a low MWL level. From a low MWL level, participants seek out a higher MWL level. And from a medium MWL level, preference for transitioning to a high or low MWL level varied by participant, but each participant had their own preference.

4.3.2 Sustainment is an Issue. It seemed as though a reason that participants sought fluctuations between MWL levels was driven by experiences of sustaining any MWL level for 'too long,' which resulted in negative consequences. These related to wellbeing, work output, mood, and perceptions. Burnout, for example, was a commonly reported consequence: *"Up until very recently I would literally say … 'this is what I want to achieve at the end, this is what I need to do to get there' and then I'll just do it regardless of whether I've worked a long day … But then I think that's ended up leading me to get burnt out before so actually since I've be furloughed, I'm trying to aim for more of a balance. So for instance on that Thursday [during the previous week] when I had a really hectic morning, or a really intense morning, I just decided to put everything away and just went out for a really casual jog … It was quite a good way to switch off"* (P2). The passage above from Participant 2 is an interesting reflection on the consequence of prolonged MWL and other experiences in their life, and the kind of goal forming that we think may develop in more detail with future wearable technology. Now, P2 purposefully inputs periods of low MWL as breaks in order to counteract the negative effects they have recognised.

Sustaining a high MWL level was also commonly associated with feelings of fatigue: *"I remember a couple of weeks ago there's one day where I was really focused on something, and I think it was*

a four hour meeting that I was in, and I had to be on the ball all the way through that four hour meeting, and I remember at eight o clock that night sitting there and going 'I need to go to bed,' because I'd just kind of completely gone" (P19). After sustained periods of high MWL, many participants reported feeling more likely to put off non-essential life tasks, such as the washing up: *"Things like cooking dinner I suppose you have to do it, you have to just get on with it but I will, if I've had like a really long day and then it's been like a long evening, I'd probably just be like 'No I'll leave the dishes and I'll leave the washing' things like that I do have less motivation to do [after sustained periods of high MWL]."* (P14)

Participants reported experiencing negative moods as the product of sustained high MWL. Participant 17, for example, said: *"I might not be at my best behaviour with others. I don't vent out but still I don't reply quite politely or if anyone asks multiple things I get irritated, so that is a downside of high mental workload."*

Participants also reported resentment towards their work, or a loss in the quality of work output as a consequence of sustaining a high MWL level; this consequence is different to the other consequences outlined so far in the sense that its affects take place during the high MWL level itself rather than as a wider implication. Participant 12 described both of these consequences: *"With copywriting I love it but I feel if I just spend ridiculous amounts of time doing it without a break I'd become almost, not detested, but I wouldn't feel as passionate or as loving towards it, for want of a better word. And after a certain amount of time, I think my output and quality of work would definitely decrease as well due to not having that rest or time away from the screen to focus."* (P12)

Some participants even reported physical health consequences from sustaining a high MWL level: *"Last week I had a really urgent deadline and because I knew it had to be with a client by the end of the day, I was working super efficiently and the director was doing it alongside me, but at the end of the day I was just dead, like exhausted, had a headache ... after feeling the pressure all day by the end of it yeah I had a headache and I kinda felt a bit spaced cause I was just focused on one thing all day and it was very intense and then yeah, I really think the headache was really related to concentrating on one thing so solidly all day"* (P13). So by the end of Participant 13's period of sustained high MWL, they were not only feeling fatigued, but also suffering from a headache and not functioning to their perceived normal level. This really captures the type of physical health consequences that sustaining a high MWL can have. Not only were physical health consequences reported, but Participant 16 related sustained high MWL with mental health consequences: *"I don't think it's something [being at a high MWL level] that's sustainable for huge periods of time ... I don't think it's something that's particularly healthy for long periods of time ... I think people can really suffer in terms of their mental health when you're operating at such a high level for a long time ... It's such a high pressure because you're just operating at a level where you're just waiting for something to go wrong."* It appears P16 associates high MWL with pressure (see theme two), and sustaining the pressure is the factor which can have negative mental health consequences for them.

Sustaining *low* MWL levels also had negative consequences for our participants in terms of how they perceived their experiences of the level. Participant 2 reflected on their recent experiences of how their perceptions of MWL were shaped by sustaining a low MWL level for too long: *"Whilst I was furloughed basically everything was just a low mental workload, I didn't really have much to do, and I don't find that enjoyable because I feel like you're not achieving something or like there's not really not much purpose to it. But then since I've started working again and since I've started training more again, I think when you have lower periods balanced with higher periods it makes the lower periods more enjoyable, more relaxing, cause you've actually got something to relax from and almost they feel like earnt or deserved ... I think you need to have the highs and the lows to enjoy both and I don't think life would be rewarding or enjoyable if you are constantly sat at either end of the spectrum"* (P2). Participant 2, while furloughed, found themselves operating at a low MWL level constantly, and their experience of that level was perceived negatively in terms of unproductivity and dissatisfaction. When their normal activities resumed again, and their daily MWL levels were varied, the low MWL experience was perceived in a much more positive way. Participant 16 reported a similar experience: *"I think I can enjoy it [low MWL] when I can put it in context to a high mental workload. I think for me it's a bit like if every day was Christmas I wouldn't enjoy Christmas"* (P16)[7]. Participant 16 was going through a quiet period at work (as a Programme Support Officer) which predominantly consisted of low MWL levels. They describe how without the balance of high MWL, low MWL loses its enjoyability (see theme two). Thus, both of these passages highlight that the low MWL feeling can be influenced by how long the level is sustained for.

In terms of medium MWL, while it was considered as the most sustainable level (see theme one), sustaining it for 'too' long still left some participants missing the full level of excitement which was associated with operating at a high MWL level: *"Being at that medium is good, but it's even better when you've got the context of the thrill of sometimes having to be at that greater capacity"* (P16). Participants who sought out low MWL from medium MWL (as described in The MWL Cycle) seemed to require low MWL levels as a break, suggesting that sustaining a medium MWL level is still fatiguing: *"I feel like medium mental workload you're kind of balanced but eventually I'd be like, 'yeah I just need a little break'."* (P13) However, the reasons for seeking out a low MWL level from a medium MWL level were not fully established, and thus issues with sustaining a medium MWL level were not revealed in detail within our data.

To summarise this subtheme, sustaining any MWL level for too long resulted in negative consequences. These related to wellbeing, work output, mood, and perceptions. Specifically, sustaining high MWL for too long was associated with: burnout, fatigue, negative mood, increased resentment, reduced work quality, and decreased physical and mental health. Sustaining low MWL was associated with: decreased enjoyment, decreased productivity, and decreased satisfaction. Sustaining medium MWL was associated with a lack of excitement and potential fatigue.

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[7]For clarity, in this case Christmas was being referred to as a special occasion, which wouldnt be special if it was regular, as opposed to referring to Christmas as being specifically high workload or low workload

4.3.3 Each Level Serves a Purpose.

The final subtheme outlines the reasons why each MWL level is important to include in the MWL Cycle. We found that each level of MWL serves a different purpose.

High MWL was related to positive implications for work and internal perceptions. Many participants associated high MWL with increased work output: *"I feel the most productive, I get more things done. So like times when we used to go into the office, it sounds like a long time ago, I could go in and if I had like three hours of really high mental workload, I could be really productive [and] I could come back home by lunch because I finished what I wanted for that day"* (P7). As well as speed of output, quality of output was also associated with high MWL in our participants: *"Often by operating at a high level of demand on yourself I found the pace of it brings a greater quality in your work that isn't there when you're operating at a two or three as well. I find that demand often spurs me into doing some really great pieces of work."* (P16)

Perhaps more important than 'better' output, high MWL was also associated with harder tasks that cannot be completed at a lower level of MWL: *"I think when I'm at a medium mental workload it refreshes your brain enough to feel up for taking the plunge with some higher mental workload tasks. I think sometimes you go, 'Alright, I am going to find some time to do this other thing,' because you're not being overloaded by loads of stuff, you can start to think again a bit more creatively which, in some instances you can do in low mental workload as well, but I think it's quite a nice feeling to feel like you're enthused about doing some harder things"* (P18). From the passage above, Participant 18, along with several participants, associated high MWL with challenging tasks, and indeed sense of achievement: *"I think if you've done something in the high space generally if you were to evaluate at the end of the day, if you've managed to achieve something when you've had a high mental workload, generally you feel more exhausted, but you almost feel more happy that you've managed to achieve something which is generally quite taxing. So, I'd probably say there's more of a degree of self worth at that high mental workload element"* (P19). Feeling that sense of achievement was almost like an indirect effect of high MWL for many, as the high level is associated with taxing output which is then associated with a sense of achievement if the task is completed satisfactorily.

We also saw that low MWL is an important level to obtain for a number of reasons. Firstly, for our participants, low MWL was important for a mental rest and recovery: *"Now that I'm working at home I just make sure that I build in tea breaks and loo breaks and things like that so I can refresh"* (P10). Participant 10 describes how they actively ensure there are periods of low MWL in order for them to refresh and recharge before entering higher MWL levels again. Equally, participants often reported that low MWL could be used in preparation for a high MWL level: *"There are days like last Thursday where I need to go home without anything to do so I can use that day to be more relaxed and get energy for the next one"* (P9). Participant 12 described these breaks, in particular, as 'clearing the mind': *"I do definitely try and seek out tasks or moments where I can just lower my mental workload level … If I do have a break the first key thing is to just get away from my screen, that mental disconnection from work, from being in front of the computer, from being sat down in a set position looking at the same windows and walls. Yeah, just even just going outside to grab some fresh air, it gives me time to just come back with a different perspective or if I'm struggling to get motivated or*

get my workload at a decent output, just coming back with a different perspective, different mindset … Recharge the batteries."

In many cases, low MWL was used as a reward: *"Something I've noticed [during] lockdown, I kind of set myself one or two large tasks each day, or a large task, and if that's done, I'll just chill out rather than trying to get loads more"* (P1). This is important given that reward-based behaviour is often intrinsically motivating for some people.

For medium MWL, the level served to balance the characteristics of the low and high levels. It was regarded as the most sustainable level and had positive implications in terms of productivity and personal perceptions; Participant 6 sums up the implications of medium MWL: *"I think it's the best place to be from a personal and a productivity point of view I guess."* (P6)

In summary of this subtheme, it appears that different MWL levels do different and important jobs. High MWL was associated with increased work output quantity and quality, harder tasks, and a sense of achievement. Low MWL was associated with rest and recovery, preparation, and reward. Medium MWL was associated with productivity and positive perceptions.

4.3.4 Summary.

In the theme presented, our findings show that there is a Cycle for MWL (Figure 2), where individuals require MWL fluctuations in particular patterns. There are negative consequences of sustaining levels for 'too' long (particularly low and high levels), and there are reasons why each level is important to incorporate into the cycle. This theme furthers our understanding of what type of goals we should aim for in terms of our MWL lives, as identifying the cycle right for each individual could result in a more sustainable, efficient, and satisfying way of living and working.

4.4 The Cycle Can't Always be Facilitated

We have outlined that fluctuations between MWL levels are important, but it appears that they are not always possible. Life, internal, and external factors were found to interfere with achieving the required, or desired, MWL levels. This was typically by either causing participants to remain operating at a certain level, or preventing them from achieving desired changes.

4.4.1 Life Factors.

Two participants provided particularly rich accounts of how their perceived ability of MWL was affected by medical factors. Participant 18, a Voluntary Services Deputy Manager, reflected on how they felt that their capacity for MWL was decreased: *"I started IVF treatment last week so it was really interesting for me that my capacity for mental workload went through the floor. So you'll see I had a few really bad days [in the subjective ratings], but there was nothing bad that happened on those days that's out of the ordinary for my work. There were peaks and troughs in the mental workload coming in, but when there was a small peak, to me it was a massive peak and my brain just went, 'Ahhhh.' Last week, might, in hindsight, not have been the best week for me to study for you because it was very visceral, it was very physical, the feeling of complete overwhelm that came with like three people asking me things at once, which I would normally need a lot more things for that to happen to me I think. Yeah, pile hormones into your body, who knew it would change your personality a bit ((laughs))"* (P18). From
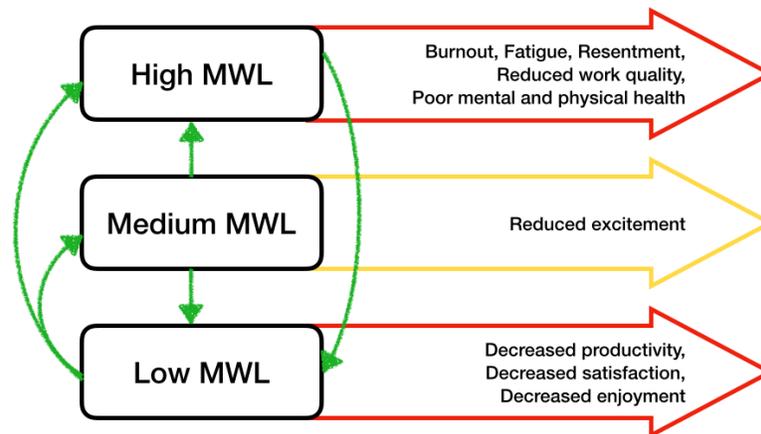
Figure 2: Diagram showing the apparent Mental Workload Cycle experienced by participants, and the consequences of sustaining each level for too long.

Participant 18's passage, we see that undergoing hormonal medical treatment seemed to implicate their experience of operating at 'normal' MWL levels. They found that tasks which would normally require lower levels of MWL instead were experienced as high MWL, which felt overwhelming. On the other hand, Participant 3 did seem to have perceived control over their MWL levels, but purposely avoided operating at a high MWL level due to exacerbated negative consequences: *"I'm on long term medication and the main side effect is somnolence, which is tiredness, but not a feeling that you're about to fall asleep. I've lived with it long enough now that I just take it in my stride, I don't feel like I change anything day to day, but I have had to adapt and I think that might explain one of the reasons why I avoid fives [the highest MWL level] because I'll just get exhausted. I aim for three [medium MWL] and I'm happy with a three, because I know I can sustain it. In my previous job, when I was probably under a lot more periods of four [high MWL], I had to come home midweek and sleep for the entire Wednesday afternoon ... It's a permanent state of being slightly subdued and I think it has been really interesting to see for me this week how much I seem to, without having realised it, maybe I adapt my workload levels to what I feel I can actually achieve and sustain"* (P3). So Participant 3 described their perceived inability to operate at high MWL levels due to the side effects of prescribed medication; if they did reach a high MWL level, they feared the consequences that would have on their life.

Some participants reported that exercise affects their perceived ability to operate at a high MWL level: *"I do tend to find in the mornings if I do go for a run prior to work my overall output and mental capacity for workload is a lot higher. I think that I've started the day off well and I've set out to achieve something and I've done it, so I seem to almost take that into the working environment"* (P12). While exercise is kind of a pre-workload activity, it also appears that e.g. music, as a concurrent context, might have some effect on some participants' perceived ability of reaching certain MWL levels: *"I play music to help me to concentrate"* (P8). With a small number of comments about the use of music to facilitate achieving MWL levels, this might be a factor that could be explored further.

4.4.2 Internal Factors. As well as life factors affecting the obtainment of certain MWL levels, internal factors were found to have the same effect. Participants often reported that, while aiming for low MWL, their level was elevated by internal thoughts which were unrelated to the activity they were doing: *"I'll go to sleep, well not go to sleep, I'll think about work in bed which is always annoying, and particularly when you have very transactional work cause it's not always one story line that you're thinking about. You're not thinking about a project, you're thinking about, 'Do this, do that, do this, do that,' and that's really annoying cause it's like a cacophony of thoughts all at once, it's just not conducive to sleep ... Literally just in my head whilst I'm in bed I have a mental workload which is ridiculous."* (P18) An increase in MWL level due to internal thoughts was reported by many participants, and was shown affect obtaining certain MWL levels.

Another factor that participants often reported as being a barrier to achieving a high MWL level was that reaching a high level requires effort: *"When I have high mental workload I have to be fully concentrated, so it's something that I have to plan and something more about will power ... Sometimes it's difficult to get to that and I find it difficult to concentrate, I get distracted"* (P11). So Participant 11 reflected on how achieving a high MWL level takes effort in terms of planning and internal will power. Sometimes, they struggle to reach the high MWL level, even though they try. Enjoyment of the task was often the factor that affected whether this effort barrier was easily overcome: *" If I'm enjoying it [a high MWL task] it's like intrinsic motivation ... I do enjoy some PhD work and that's the stuff I'll keep doing, the stuff's that's sustained longer is because I've enjoyed it"* (P1). For future work, we could speculate that enjoyment could result in either not maintaining MWL levels for long enough if it is a task that they do not enjoy, or possibly maintaining certain MWL levels for too long if it a task they do enjoy, both affecting the balance of the cycle.

4.4.3 External Factors. As well as life and internal factors potentially affecting the MWL Cycle, external factors also appear to interfere with the balance of levels. External demands were reported by participants which required sustaining MWL levels: *"I had to do it [maintain a high MWL level] in the lab sometimes, it's like you go there [at] nine o clock in the morning and you can't go home till five in the afternoon without lunch because you cannot turn off the reactor."* (P9) From Participant 9's passage, it appears that they are sometimes placed in a situation where because of the demands of the task, a high MWL level must be maintained, which does not facilitate the balance of MWL levels.

As initially reported in theme two, pressures were reported to result in sustaining MWL levels rather than fluctuating. Participant 19 noted that a period of leave from work left them feeling unable to avoid sustaining a high MWL level when they returned. *"Sometimes you can't avoid it [sustaining a high MWL level] like, perfect example, so I'm on holiday from Sunday to Wednesday this week and I'm back Wednesday night. I've got really important meetings Thursday and Friday, external meetings and internal meetings, my diary is full. I couldn't really get away from that because I'm away Monday to Wednesday."* (P19)

Similarly, many participants reporting having to sustain high MWL levels simply until their task was completed (regardless of cause): *"I'm happy to maintain those [high MWL levels] until it's done. Usually I do allow myself buffer time, for example if I think that this specific section is going to take me two days, in my mind if I enter in a high mental workload area then I finish in one day or half a day, I'm like, 'Ok this is good, I'm fine with it,' so I believe it's more goal orientated than time orientated in my case"* (P7). Thus it seems that Participant 7 was willing to maintain a high MWL level for as long as it took to produce what they perceived as a satisfactory amount of output (as discussed in theme two). We could speculate again that this could result in sustaining a certain MWL level for too short or too long for the individual. It is worth noting that sustaining MWL levels instead of fluctuating between MWL levels does not only apply to high MWL with our participants; for example, as previously mentioned, Participant 2 had a period of sustaining low MWL levels because of external factors as they had be furloughed from work and their sporting activities had been paused.

4.4.4 Summary. Whilst participants benefited from fluctuating between MWL levels, this was not always possible. Life factors, including medical reasons, exercise, and potentially music, internal factors, including thoughts and effort, and external factors, including circumstances and task completion, often interfered with fluctuations. This was likely to result in the negative consequences described in theme 3 as levels were either sustained or not achieved.

5 DISCUSSION

This study investigated lived experiences of MWL with the aim of furthering our understanding of how tracking such "brain data" could be used to improve our work performance and lives. Four themes were identified that provided a rich insight into MWL.

Theme 1 outlined that there were different general perceptions of high and low MWL levels, in that different participants had either positive or negative perceptions of the same level. In contrast, all participants regarded medium MWL positively. Theme 2 identified

four factors (pressure, enjoyment, outcome, and location) that could change the initial perceptions of the high and low MWL levels from positive to negative, or vice verse. These themes relate directly to RQ1, as they further our understanding of how experiences of MWL are perceived.

Theme 3 presents an apparent MWL Cycle, where findings identified the necessity of fluctuating between MWL levels which tended to occur in specific patterns. Fluctuations prevented sustaining any level for too long as this could have negative consequences on oneself or work output (e.g. fatigue or feeling unproductive), and allowed individuals to benefit from the different positive characteristics of each level (e.g. a sense of achievement or time to recover). The findings from this theme contribute largely towards understanding the impact that MWL may have on our lives and work (and the impact that our lives and work may have on our MWL performances), and increases our understanding of what we should aim for in terms of MWL (RQs 2 and 3).

Theme 4 identified three factors (life, internal and external) that could prevent individuals from achieving their Cycle fluctuations by decreasing the opportunity to fluctuate or affecting the ability to operate at certain levels. This finding contributed towards RQ3, as although we know what we 'should' typically aim for in terms of MWL, there may need to be other goals set to prevent the negative outcomes that may arise from not fluctuating between levels in those people who struggle to achieve the ideal fluctuations.

Whilst our main contributions derive from themes 3 and 4, themes 1 and 2 are important for two reasons. Firstly, as far as we are aware, no research has investigated MWL from a 'people perspective,' in terms of how MWL is qualitatively conceptualised by those who experience it; there is a large body of MWL research [46, 56, 66], but the focus remains on quantitative studies. Increasing our understanding of the experiences behind the numbers may contribute to greater progress in these research areas, such as increased understanding of what contributes to overload and underload. Indeed secondly, and for this study, themes 1 and 2 lay the foundations for understanding people's approaches to MWL in their lives, such as high MWL avoidance because of associations with stress. When developing the MWL Cycle, having an understanding of the different perceptions of MWL enabled a richer insight into why having MWL fluctuations are preferable and how Cycle preferences may vary between individuals, which is discussed in more detail below.

5.1 Personal informatics and BCIs

Current pBCI neurotechnology available to consumers (to help people e.g. focus or meditate) are tailored around helping users to achieve a certain state in the present moment. What we have investigated is how tracking MWL data over longer periods of time (days/weeks/months) could contribute towards making improvements in our lives, as a form of personal informatics [21, 38, 52, 53].

MWL was chosen as a concept that is fundamental in our daily lives and has a large body of research aimed at accurately tracking it in the real-world. It is likely that this tracking technology will be available as type of pBCI in the relatively near future [2, 3]. Its current application applies to improving performance at work,

especially in safety-critical jobs [3, 66], but the findings from our study suggest that tracking MWL from a broader life perspective could have positive implications for our wellbeing and performance on tasks. This is because if we keep track of our MWL levels and aim to adhere to the MWL Cycle that is optimal for us in terms of fluctuations between levels, we could avoid the negative consequences that come from sustaining levels for too long, and reap the rewards of the benefits that each level can have on our work and lives. Perhaps people would, for example, feel less burnt out and resentful, and feel more rested and efficient.

Our early data does seem comparable to physical activity, in the sense that if you don't exercise enough, or you exercise too much, there can be negative implications for your health, but striking the right balance of physical activity has endless health benefits [64]. It seems as though finding the right balance of 'mental exercise' in terms of MWL could have numerous benefits to our lives as well; similarly to physical activity, we should aim towards incorporating periods of rest, intense, and moderate activity into our lives.

Additionally, the findings from this study also suggest that people could aim to structure their MWL in ways that would optimise their performance on certain tasks. For example, if someone wanted to optimise their performance on a high MWL gaming session, they could limit the amount of high MWL they have before they game in order to make sure they don't get fatigued from spending too much time at that level. Instead they could structure their time before the gaming session to include a period of low MWL to serve as a period of mental recovery and preparation before performing the high MWL task. Thus, the identification of the MWL Cycle has contributed to our understanding of how MWL impacts our daily lives and what goals we should set in terms of MWL; the direction of future MWL pBCI technology could be guided by these findings in terms of what data and goals could be useful to track.

More speculatively, once we have access to such brain data as personal data, habit formation may be interesting to study [59]. Notably in the present study, we saw that people had goals to actively break up high MWL periods, and designing technology to help people measure or recognise the impact of break taking on subsequent MWL or productivity could be beneficial. Equally, as with people living a sedentary physical lifestyle, technology could help people to comprehend the scale of their prolonged low MWL periods so they can work towards improving their MWL activity. A common concern in research at the moment is the impact of mobile phones on e.g. mental health and sleep [45], and this type of pBCI technology may enable people to track the effects of activities on their behaviours, e.g. the impact gaming has on their ability to study. Whilst there is much more we need to understand before detailed specific, individual MWL goals can be determined, these results show the nature of the goals we could set and how they may contribute to life improvements.

5.2 Holistic MWL for neuroergonomics

We believe this study has illustrated how important it is to consider MWL as a whole rather than focusing narrowly on MWL limits within specific tasks. Considering low, medium, and high levels throughout the day, and considering them both outside and inside the workplace, seems important for understanding performance

on isolated work tasks. If MWL levels outside of the workplace are not considered, we cannot understand the needs of people at work, and why they approach tasks in the way that they do. Our results suggest that sustained periods of (e.g.) high MWL outside of work (perhaps with coordinating family life, as was reported in the study), can lead to fatigue more quickly during a work task that requires high MWL, as the overall time spent at that level was greater than the time just spent on the work task. In essence, this could explain why performance on the same task completed on different days can vary. Also, we saw from theme 4 that certain factors can interfere with people's ability to function at certain MWL levels, which is also likely to contribute to varied task performance. This could mean that even if tasks are designed to be within a manageable MWL level, factors taking place outside of the workplace might mean that people sometimes find them unmanageable. These findings echo work in related fields looking at the relationships between demands at home and safety at work [33], and visa versa [16, 17], as well as the participants in this study who described how carefully managed rest, both at work during breaks, and in the evenings, was needed to manage work. Thus, considering MWL levels in between the extremes of overload and underload [55, 66] and taking a broader life perspective of MWL could be essential for deepening understanding of factors that contribute to the 'redline' of these states.

As the findings from the study showed, participants discussed their strategies within work tasks (at work and at home) that aimed to break up their high MWL tasks with low MWL tasks in order to both a) work longer at high MWL tasks overall, and also b) to complete lower MWL tasks at ideal moments. A key factor in research focusing on the Future of Work, is to decompose work such that different sized tasks can be handled conveniently as e.g. microtasks [62]. This seems beneficial for people that have agency in their work, such as many office workers or self employed people. There are many jobs, however, such as air traffic controllers and train signal operators that have been carefully organised into shift patterns with predetermined breaks, where it is the responsibility of the employees to manage their ability to sustain MWL accordingly. If MWL is considered from a more holistic and person-centred perspective, tracking MWL outside of work may enable workplaces and employees to manage MWL more effectively during work tasks. We therefore believe that tracking MWL in everyday life would not only be useful as a form of personal informatics, but could also be useful for improving safety and performance in safety-critical jobs.

5.3 One MWL size does not fit all

As the primary contribution from this study outlined an apparent Cycle, where we ideally vary our day-to-day MWL in particular patterns, it enabled the identification of the types of goals we should set in our 'MWL lives' (outlined above). We generally know what is healthy for everyone in terms of physical activity; e.g. walking 10,000 steps each day is, even if an oversimplified goal, good for us. But it is clear that participants had different preferences in their MWL lives, such as those who regarded low MWL as positive vs those who regarded it as negative. It should therefore be considered that the 'right' amount of MWL might differ between people. We

saw that some participants perceived high MWL as overwhelming, and so these individuals might benefit from less high MWL fluctuations compared to those participants who perceived high MWL as exciting. So as cognitive activity is not tangible like physical activity, there is added complexity in tracking data and future BCI technology that passively tracks cognitive activity for use as personal informatics will only suit the needs of all users if the preferences for each individual are taken into account. As some research has noted though, keeping generally active is better for cognition and cognitive health with ageing [22, 23], and we speculate that this would also be true in terms of MWL; older participants were not the focus of the current study, but investigating how MWL tracking could be used to avoid a cognitively sedentary lifestyle in this population would be an interesting area for future research.

One insight from our work further emphasises the 'subjective' mental workload experiences. Much MWL research relies on the subjective reports of participants, and our work explicates further a well established principle that this is individual, and different people's experience of the same demand may vary dramatically, even for themselves depending on their recent MWL levels. Indeed, Maior et al [40] reported anecdotal evidence that some people found the same air traffic control demand stressful and difficult, while others reported it as challenging and fun. Our second theme expanded on these differences, and perhaps sense of pressure, for example, should be an element that is also captured to better interpret MWL ratings.

MWL ratings are often used as the 'ground truth' for labelling states for machine learning, for classifying MWL state according to physiological data. The variation between people, and indeed between the experiences of the same work on different days by the same person, emphasises the challenge machine learning MWL, and would strengthen the reasoning as to why it often achieves low classification accuracy for mental workload tasks [7]. Indeed, the consumer technology that is available tries to apply generalised initial machine learning models to work well for all users, before learning more data from the individual user. More importantly, though, the contextual experience of MWL highlights the challenge of taking many examples of a same subjective rating even from the same person, and presuming that the same physiological response levels will be present. Indeed, these factors highlight Sharple's recommendations [55] that to understand workload, we (and any consumer neurotechnology) need to understand a lot more about the 'whole system' that impacts a given moments experience of workload, rather than focusing purely on the relationship between controlled task demand and resources needed to achieve it.

5.4 Future research and limitations

Although we currently lack the exact wearable devices to measure MWL longitudinally in everyday life, this research has contributed to understanding the nature of how tracking MWL data could be useful as a form of personal data. However, the study was initial and exploratory; much more research is needed to build upon these findings.

The participants selected for this study were office workers as believed this sample would be likely to have MWL variety in their lives due to work being cognitively based rather than physical. We

also presumed that those with MWL variety in their lives would be most inclined to track that data as personal informatics. It would be useful to investigate whether similar themes emerged from other types of worker, and whether similar improvements could speculatively be made from tracking MWL. Similarly, office workers as a sample was very broad, so research could look more narrowly into MWL within different office-work professions.

For an IPA study, our sample size was considered large [58] which might have sacrificed some richness of individual accounts. We saw benefit in transferring each participant who had previously experienced MWL tracking to this qualitative study as they each carried over an unusual insight into their MWL experiences, and we aimed to remain as idiographic as possible. Indeed, our future work includes completing the analysis of the behavioural and logged data of participants in our study, in similar ways to research by Mark et al on experiences of stress [41].

The MWL Cycle appears to reveal a lot about the impact of MWL in our lives, but more research is needed to develop understanding at a finer level. An arguably common consensus is that having lots of high MWL in our lives is 'good' in terms of work output; our findings did somewhat validate that high MWL does improve work output in terms of quality and quantity. But we lack understanding about how much high MWL (and low and medium MWL) would benefit us before they begin to negatively impact our wellbeing and work. Research into the length that individuals should sustain each level for and the amount of fluctuations that is healthy to incorporate into each day would provide a better understanding of what we should aim towards in terms of MWL.

It was also not established which level of MWL participants sought out after low MWL or indeed if a specific one is the most beneficial; it was clear that higher levels were pursued, but not whether these levels tended to be high or medium MWL. And though medium MWL was consistently described as sustainable, were breaks still needed at that level? Theme 4 also perhaps opened up more questions than answers, in the sense that it tells us the circumstances in which people are not able to fluctuate in their Cycles, but it does not answer what can be done to mitigate the effects of this. Finally, when considering the design of MWL trackers, it is important to consider the different perceptions of mental workload between individuals, in terms of how some consider (e.g.) low MWL as positive, and other consider it negatively. In these instances, the ways that data is presented to users could benefit from differing between types of user; for example, providing more positive reinforcement when people with negative perceptions incorporate the level into their Cycle.

It will be exciting to see further research progress the understanding of MWL from a life perspective so that we can further develop our knowledge about how the data can be used to optimise areas of our lives. We expect future work, when more generalised mental activity tracking devices are available in practice, to unravel a lot about lived MWL experiences [21, 53], especially in relation to other devices in a quantified self ecosystem.

6 CONCLUSIONS

With the bloom of consumer BCI technology on the horizon, it is important to establish how the data can be used to facilitate life improvements. This study moved away from considering just short

instances of MWL within a task and provided detailed insights into lived experiences of MWL. Findings suggest that considering MWL from a holistic and person-orientated perspective is important for understanding aspects of our wellbeing and task performances. Based on an apparent MWL Cycle, healthy and efficient outcomes come from aiming to fluctuate between MWL levels in particular patterns, as this prevents the negative implications resulting from sustaining any level for too long whilst enabling the positive implications that each level can provide. Whilst more research is needed, an understanding of the nature of goals we can set in terms of MWL has been developed. By taking into account people's perceptions and the factors which affect their MWL ability, this study strongly suggests that tracking MWL data is not just useful to measure during isolated work tasks.

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Data Access Statement: Due to concerns over protecting the anonymity of participants, a protected dataset is available for researchers only upon request, with suitable ethics already in place. This contains: anonymised transcripts of interviews.

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A   APPENDIX - SEMI-STRUCTURED INTERVIEW ROUGH GUIDE

All answers were probed in depth. Graphs were used as prompt whenever needed for depth. Examples were encouraged.

General

- Before going into more specific questions, did anything in particular stand out to you about your mental workload experiences?

High MWL

- What did it feel like when you were experiencing a high mental workload level?
- Was the feeling the same for different instances of high mental workload? Or did the feeling of high mental workload depend on the task?
  (If answer depend on task) Why?
- Do you enjoy periods of high mental workload?
  Why? When? etc
- Could you maintain a high mental workload level for a long time?
  Does it depend on task? Why? Does anything affect your ability to maintain the level? etc
- When you're at a high mental workload level are you happy to stay at that level or do you seek out different levels?
  (If seek change) When? Why? Would anything happen if you couldn't change level? How would you feel? Would your task be affected? etc for follow up
  (If happy to maintain) Why? What would happen if you were made to change? How would you feel? Would your task be affected? etc
- How would you feel if you realised that you may have a whole day of high mental workload levels ahead of you?
  Would you take any actions? etc
- When you've had periods of high mental workload, would you say it affected any aspect of your behaviour or cognition or life?
  Follow up eg if yes then what impact, methods to mitigate etc.
- When you've had periods of high mental workload, do you feel as able to address life tasks? Such as the washing up.
  Follow up why, how to manage, etc
- Before we move on, are there any particular experiences of high mental workload that you would like to talk about?

Low MWL and Medium MWL

Same set of questions asked for low and then medium MWL levels.