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Recovery as an explanatory mechanism in the relation between acute stress reactions and chronic health impairment

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This contribution aims at shedding light on the mechanisms that may underlie the relationship between acute reactions to stressful work characteristics and employee health in the long run. Recovery, a process of psychophysiological unwinding after effort expenditure, is considered a vital link in this relationship. This link is explained on the basis of assumptions from theories on effort, recovery, and sustained activation. It is argued that recovery after work (external recovery) is particularly necessitated when recovery opportunities during worktime (internal recovery) are insufficient. It is further argued that two conditions may impede the recovery process by sustaining physiological activation, prolonged exposure to work demands (working long hours) and cognitive stress-related processes (such as rumination). These theoretical assumptions are substantiated by empirical support from previous laboratory and field research. It is concluded that the chronic situation of sustained physiological activation and incomplete recovery is an important pathway to chronic health impairment.

Key terms allostatic load; effort; load reaction; nonwork; psychophysiological; recuperation; sustained activation; unwinding; work.

It is well-established that employee health is adversely affected by stressful psychosocial work characteristics. Longitudinal research guided by the influential job demand–control model (1, 2) has demonstrated that being exposed to a work environment characterized by high psychological demands and low job control (so-called "high-strain jobs") is associated with increased levels of physical and psychological health problems across time (3, 4). Research inspired by the more recent effort–reward imbalance model (5) provided evidence that a combination of high effort expended at work and low job rewards (low career prospects and poor job security) are related to subjective health complaints, coronary heart disease, and absenteeism (6). [For reviews, see the reports of Tsutsumi & Kawakami (7), and Van Vegchel et al (8).]

In the linkage between exposure to stressful work characteristics and adverse health, stress-related physiology seems to play a crucial mediating role (9). Exposure to job stressors may directly elicit potentially harmful physiological responses, such as increased blood pressure and elevated catecholamine and cortisol excretion levels, but such responses are also caused indirectly via unhealthy lifestyles, such as smoking, alcohol consumption, unhealthy diets, and lack of physical exercise. The main physiological explanation for the relationships between stressful work characteristics and, for instance, cardiovascular outcomes that can be derived from the job demand–control model (1, 2) and the effort–reward imbalance model (5) refer to "active distress" or a state of arousal activating the two stress-response bodily systems, that is, the sympathetic-adrenal-medullary (SAM) system and the hypothalamic-pituitary-adrenal (HPA) system. However, the occurrence of these stress-related physiological reactions is—in principle—short-lived (10). When exposure to (stressful) work characteristics ceases, these acute reactions decrease and often disappear within a certain period of time. Thus, in order to understand and explain fully how (stressful) work characteristics result in health impairments in the long run, we need an additional explanatory mechanism.

In this contribution, we present a conceptual approach to (incomplete) recovery as an explanatory mechanism underlying the relationship between acute physiological stress reactions and chronic health impairment (figure 1). Recovery is seen as an important

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intervening variable in the hypothetical causal chain of (i) stressful work characteristics, (ii) the development of acute load reactions, and (iii) chronic load reactions (poor health). Earlier research and practical interventions addressing rest breaks, workhours, and shift work (14) have, at least implicitly, acknowledged the role of recovery in protecting individual well-being, health, and performance capabilities. [See Tucker (11) for a review on rest breaks and Sparks et al (12), van der Hulst (13), and Totterdell et al (14) for reviews concerning workhours.]

First, we explain the relevance of the recovery concept by drawing on assumptions from relevant theories on effort, recovery, and sustained activation, that is, the effort–recovery model (15) and the allostatic load theory (16). Second, we discuss how recovery can occur in the context of work and nonwork. Third, we discuss the conditions that may impede the recovery process by prolonging physiological activation, that is, working long hours and cognitive processes such as ruminative and anticipatory thoughts about job stressors. In all of these sections, we substantiate our theoretical assumptions by providing empirical data (without aiming at providing an exhaustive overview of empirical research on effort and recovery). Finally, we draw some main conclusions and discuss suggestions for future research.

Recovery as a crucial concept

The effort–recovery model

One of the theories that explicitly stresses the important role of recovery in the transition from acute to chronic load reactions is the effort–recovery model (15). Its core assumption is that, initially, normal load reactions that are unavoidably associated with effort expenditure at work (such as accelerated heart rate and fatigue) can develop into more chronic load reactions in cases of continued exposure to workload and incomplete recovery. The essence of recovery is that the psychophysiological systems that were activated during work will return to and stabilize at a baseline level, that is, a level that appears in a situation in which no special demands are made on the individual. Accordingly, recovery is a process of psychophysiological unwinding that is the opposite of the activation of psychophysiological systems during effort expenditure, particularly under stressful conditions.

Under optimal circumstances, recovery occurs after a short respite from work. However, under certain circumstances, the recovery process may be incomplete, and the psychophysiological systems remain activated before having had a chance to return to and stabilize at a baseline level. The worker, still in a suboptimal state (eg, still tired of the previous work period), must invest compensatory effort to perform adequately at work. This compensatory effort shows an increased intensity of load reactions and initiates an even higher demand on the subsequent recovery process. Consequently, an accumulative process may be started that, in due course, results in chronic health problems such as prolonged fatigue, chronic tension, persistent sleep problems, or manifest diseases (17, 18).

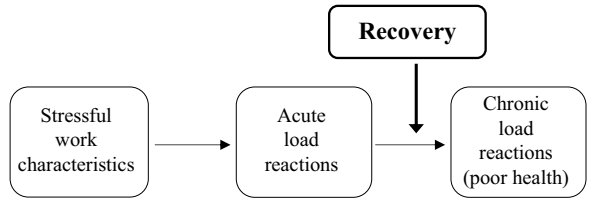

Figure 1. Model of work, recovery and health.

Allostatic load theory

Whereas the effort–recovery model (15) does not describe in detail which psychophysiological systems are crucial to the recovery process, McEwen's allostatic load theory (16) is more explicit in this regard. McEwen refers to "allostatic" systems that include the autonomic nervous system (comprised of the sympathetic and parasympathetic nervous systems), the HPA axis (with cortisol as the main indicator), the metabolic systems (eg, the thyroid axis, insulin, glucagon), and the immune system. These allostatic systems play an important role in the protection and adaptation of the organism to potential stressors. The sympathetic nervous system kicks into action during emergencies (or what is thought of as emergencies) and mobilizes the organism to act in response to the stressor. By immediately releasing the catecholamines adrenaline and noradrenaline, it contributes to increased heart rate, blood pressure, muscle strength, mental activity, and total energy consumption. Conversely, the parasympathetic nervous system is in control when the emergency is past, direct action in response to the stressor is no longer needed, and the organism is in a quiet and relaxed state, such as during sleep. It aims at restoring the undesirable or destructive effects of sympathetic arousal—heart rate slows, blood pressure normally drops, muscle tension decreases, and energy is restored rather than consumed. As the sympathetic and parasympathetic nervous systems exist in a state of antagonistic tension, the parasympathetic nervous system is typically passive during sympathetic arousal and vice versa (19). This process of maintaining a balance between sympathetic and parasympathetic activity (homeostasis), despite changes in the external environment, is called "allostasis" (20).

Disturbances in this homeostatic balance can occur in situations of repeated or prolonged exposure to stressors. Chronically sustained activation of the allostatic system may result in either a failure to shut-off (hyperactivity) or a failure to respond adequately (hypoactivity), both indicative of homeostatic imbalance. McEwen (16) uses the term "allostatic load" to describe "the wear and tear on the body and brain resulting from chronic *over*activity or *in*activity of physiological systems that are normally involved in adaptation to environmental challenge [p 37]". For instance, due to chronic or repeated stress, the immune system may dysfunction by either being not attentive enough so that infectious agents (viruses and bacteria) enter the body and cause infectious disease or by being overreactive so that the immune system itself (rather than infectious agents) causes ill health [eg, autoimmune diseases and allergic diseases (21)]. In a recent study among women working in a health care sector, higher levels of allostatic load, as indicated by higher levels of cardiovascular activity (blood pressure and heart rate), blood lipids (associated with increased risk of cardiovascular disease), triglycerides (measures of fat deposits), serum DHEAS (dehydroepiandrosterone sulfate, a functional HPA axis antagonist), and prolactin (sensitive to sleep and stress), were found in women who reported relatively poor recovery in association with fatigue and frequent sleeping problems as compared with women who reported a more favorable recovery pattern (22).

Sustained activation, incomplete recovery and chronic load reactions

The occurrence of sustained activation can manifest itself in slow unwinding processes after a stressful work period (23). One possibility of operationalizing slow unwinding is to measure subjective indicators of poor recovery such as recovery complaints, high levels of fatigue, and low sleep quality after a stressful work period. Indeed, there is broad empirical evidence that people who are facing a high degree of job stressors report more fatigue and recovery complaints (24–27). For instance, in an unpublished study of Van Hooff, Geurts, Kompier and Taris, it was demonstrated that academic staff members who expended high effort during a regular workday, experienced higher levels of fatigue during the evening hours and during the weekend, as well as lower sleep quality during the workweek. In a similar vein, Dahlgren et al (28) showed that Swedish office workers had more difficulty falling asleep (although they felt tired) and had a shortened sleep length during a stressful week as compared with a workweek characterized by low stress. A similar finding was reported for driving examiners; they reported more trouble falling asleep during the night after an intensified workday (29).

Slow unwinding may also manifest itself physiologically, such as in neuroendocrine reactivity and recovery indicators (eg, catecholamines). Two recent systematic literature reviews (30, 31) have revealed that adrenaline levels remain elevated after stressful tasks or work periods, indicating incomplete recovery. For instance, it was shown among truck drivers that catecholamine levels during evening hours were higher on workdays than on nonworkdays (32). In a classic field experiment among Dutch driving examiners with varying degrees of workload (29), it was shown that adrenaline levels were higher on days with a very intensive workload (ie, 11 examinations per day and no pauses in-between examinations) as compared with levels on the days with a relatively low or medium workload (ie, 9 or 10 examinations per day) and that these elevated adrenaline levels persisted throughout evening hours. These findings suggest that it is more difficult to unwind physiologically after a highly intensified work period. [See also the papers by Ursin (23), Frankenhaeuser et al (33), Lundberg et al (34), and Rissler (35).]

Longitudinal research on recovery that covers longer time periods is still scarce. As far as evidence has been provided, it shows that repeated incomplete recovery after a work period may lead to chronic load reactions and poor health in the long run. For example, Van Hooff et al (18) provided evidence for the accumulation of subjective health problems (eg, fatigue) over a 1-year period among workers who experienced a long-lasting situation of work–home interference, which was conceptualized as the spillover of work-related load effects to the home situation. Research using physiological recovery indicators and more objective health indicators point into a similar direction. In a sample of nurses, Ganster et al (36) found that elevated cortisol levels after (but not during) work predicted health care costs 5 years later. In a more recent study, Stewart et al (37) showed that poorer blood pressure recovery among healthy adults after they conducted psychologically challenging tasks predicted elevated blood pressure levels 3 years later (also when initial blood pressure levels and possible confounders such as body mass index, education, and lifestyle factors were controlled). [For similar findings, see the paper by Steptoe & Marmot (38).] In a prospective cohort study, Kivimäki et al (39) showed that industrial employees (initially free of overt cardiovascular disease) who reported insufficient recovery during free weekends showed an elevated risk of cardiovascular death more than 20 years later. Similarly, it has been demonstrated that not taking annual vacations is associated with a higher risk of all-cause mortality and, in particular, mortality attributed to cardiovascular disease during a 9-year period (40).

In summary, recovery is a process of psychophysiological unwinding after effort expenditure. When work-related load reactions associated with effort expenditure are high, particularly under stressful conditions, psychophysiological activation may be sustained and manifest itself in subjective reports of incomplete recovery (eg, fatigue and sleep complaints), as well as in the form of physiological indicators (eg, prolonged neuroendocrine activation and delayed cardiovascular recovery). In a situation of incomplete recovery, workers have to mobilize compensatory effort in order to perform adequately at work. The resulting accumulation of load effects may, over a longer period, result in "allostatic load", which is a primary pathway to chronic ill health. Hence, recovery appears to be a crucial link in the relation between acute load reactions in response to (stressful) work conditions and poor health in the long run.

Recovery in the context of work and nonwork

Recovery may occur in a work context, referred to as *internal* recovery, as well as in a nonwork context, referred to as *external* recovery (41, 42). Internal recovery may obviously occur during short rest breaks from work (coffee or lunch breaks). In a literature review, Tucker (11) showed that rest breaks indeed seem to be effective means of managing fatigue and maintaining performance. Internal recovery opportunities may also be provided by variety and control in the job setting. These job characteristics may allow workers to create spontaneous breaks in-between tasks (mini-breaks) and to adjust their work strategy to their current need for recovery, for instance, by switching to less demanding tasks or by slowing down their task performance when feeling tired (coping). According to Dembe (43), a lack of mini-breaks may at least partly explain the increasing rates of repetitive strain injuries among office workers. Whereas, before the introduction of the computer, office workers performed a variety of tasks providing them with mini-breaks, the incorporation of these tasks into work with a computer eliminated these breaks, increased static load, and put more strain on the musculoskeletal system. Various studies have provided—although not unequivocally (44)—evidence that low control in the job setting is associated with poor physiological recovery during and after worktime, as indicated by elevated levels of catecholamines and cortisol and prolonged cardiovascular recovery (45–49).

External recovery may occur during after-work hours, during weekends, and during longer periods of respite (eg, vacations). Time off the job may contribute to the recovery process through direct release from daily exposure to job stressors (a more "passive" mechanism) or through the engagement in nonwork activities that may contribute to the recovery process (a more "active" mechanism). Off-job time can, outside of sleep time, be classified into the following three categories (50): "work-related time" referring to, for instance, time for preparing or finishing work at home, "semi-leisure" time, that is, time for activities with a somewhat obligatory nature such as domestic activities, and "leisure" time, referring to time spent entirely according to one's own choice. Regarding "leisure" time, an additional distinction can be made between passive leisure time requiring only low effort (eg, watching television) and active leisure time, for instance, social (eg, meeting friends) and physical [eg, sports and exercising (26, 51)] activities.

Time spent on work-related activities is discussed in the next section as the most obvious category of activities limiting potential recovery time. Recent diary studies have revealed that time spent in active leisure time (social, sport or other physical) activities and, though to a less extent, time spent on low-effort activities are associated with indicators of higher recovery (eg, lower fatigue and improved well-being) before bedtime (26, 27, 51, 52).

Although research on recovery during weekends is scarce, Fritz & Sonnentag (53) showed that engagement among emergency service workers in social activities (engagement in low-effort and physical activities was not investigated) during the weekend had a recovering effect in terms of improved well-being after the weekend. However, this study also reported that, in general, recovery indicators (eg, feelings of exhaustion) had not improved after the weekend as compared with pre-weekend levels.

Vacation as a relatively long and uninterrupted period of respite from work may contribute more to the recovery process. However, surprisingly few studies have investigated the potentially recovering impact of vacation. Insofar as evidence is available, it shows that immediately after vacation, recovery indicators (eg, fatigue, sleep quality, health complaints) had improved when compared with the levels before vacation but that the gains from vacations faded within a couple of weeks after work was resumed (54–57). The scarce respite research addressing the impact of specific vacation activities reveals findings that are similar to the pattern of results emerging for activities during shorter periods of respite from work. Among white-collar workers, Strauss-Blasche et al (58) found positive associations between having pursued physical activity and social contacts (making new acquaintances) during vacations and feelings of recuperation during the first week after vacation.

In summary, recovery may occur in the context of work and nonwork (internal and external recovery,

respectively). Internal recovery opportunities are provided by sufficient (mini) breaks and job control that allow workers to reduce the necessity for external recovery. External recovery may occur during after-work hours, during weekends, and during longer periods of respite (vacation). Although simply the release from daily exposure to job stressors may contribute to the recovery process ("passive" mechanism), this process may also benefit from engagement in particularly active leisure time (eg, social, sport, or other physical) activities.

Conditions that may impede the recovery process

Besides the potentially recovering impact of work respites, as well as of activities encountered during these respites, there are also conditions that may impede the recovery process. In this section, we discuss prolonged exposure to work demands as one condition that limits available recovery time (ie, the quantity of recovery) and cognitive processes prolonging physiological activation as a condition that hampers the effective use of potential recovery time (ie, the quality of recovery).

Prolonged exposure to work demands

Prolonged exposure to work demands can result in incomplete recovery, not only because, by definition, the time available for recovery is limited, but also because a demand is made on the same psychophysiological systems that were already activated on the job. In terms of the allostatic load theory (16), the allostatic systems are in danger of chronic overactivity, producing "allostatic load". In order to recover from work-related load reactions, it seems important that, during off-job time, people engage in activities that appeal to other psychophysiological systems or do not engage at all in activities involving effort. Picture a job (eg, a web designer) that unremittingly puts high demands on an individual's cognitive (ie, conscious attentional) processes. In order to recover from work, this individual would be better off not engaging in activities after work that require the same type of effort (eg, fixing a computer crash at home), whereas activities that require physical effort (eg, exercising) or almost no effort at all (eg, watching television) would probably less impede the recovery process. Similarly, a construction worker whose job requires high physical effort would be better off avoiding engagement in activities after work that put high demands on the same physical systems (eg, moonlighting), whereas exposure to other types of demands (eg, light domestic tasks or social obligations) would less impede the recovery process.

van der Hulst's review (13) on long workhours and health showed that prolonged exposure to work demands is indeed associated with adverse health, in particular cardiovascular disease, diabetes, subjective fatigue, and subjectively reported physical ill health. Her review also provided evidence that those who work long hours show sustained increases in heart rate and blood pressure (precursors of cardiovascular disease) and disturbance of the immune system, factors that point at incomplete physiological recovery. Recent diary studies have also revealed that working long hours or working overtime is associated with subjective indicators of poor recovery, such as difficulty to relax at home, negative affect, impaired well-being before bedtime, and low sleep quality (26, 27, 59).

Although the detrimental impact of extreme overtime work has often been demonstrated, the unfavorable impact of moderate overtime hours on health and well-being has not been consistently shown (41, 60). [See the papers of Sparks et al (12) and van der Hulst (13) for reviews on the impact of long workhours on health.] There are indications that various moderators may have an impact on this relationship (61), such as personal characteristics (eg, work motivation), work characteristics (job control, job rewards, internal recovery opportunities), and the motives for overtime work (pressure or pleasure). For instance, van der Hulst & Geurts (42) concluded that moderately long workweeks (<50 hours) were only associated with adverse psychological health (poor recovery, fatigue, and work–home spillover) under circumstances of low job rewards and a high pressure to work overtime.

In summary, various research approaches indicate that working very long hours impedes the recovery process, which manifests itself in sustained physiological activation, as well as in subjective reports of incomplete recovery. However, the extent to which working moderately long hours has negative health consequences may depend on moderating variables, such as work characteristics.

Cognitive processes prolonging physiological activation

Psychophysiological activation may be sustained even when workers are no longer exposed to any job demand or stressor. In this section, we discuss cognitive processes that are related to the persistence of physiological activation. The crucial role of cognitive processes in the stress process has already been accentuated by Lazarus in his early model on stress, appraisal, and coping (62, 63). Appraisal refers to a person's categorization of a situation as being irrelevant, benign, or stressful (primary appraisal) and his or her evaluation of coping options (secondary appraisal). In their cognitive activation theory of stress (CATS), Ursin & Eriksen (64) emphasized the importance of coping with potential

stressors. They consider a general stress response as a nonspecific alarm response in a homeostatic system (65) that—only if sustained—causes "allostatic load" (16). As the stress response is experienced as uncomfortable, it drives the organism to initiate proper action to deal with the stressful situation (coping). When coping is expected to bring positive results ("positive outcome expectancy"), the stress response is reduced, and health deterioration is no longer probable. When coping options are not available ("helplessness") or are expected to bring negative results ("negative outcome expectancy" or "hopelessness"), the stress response does not fade out, and health is endangered. Thus, according to CATS (64), "negative outcome expectancy" is an important determinant of prolonged physiological activation, and a potential mediator in the relationship between acute physiological stress responses and long-term ill health. Evidence for unfavorable endocrine and immunology consequences from negative outcome expectancies stems from laboratory and field research among animals and humans (66).

Brosschot et al (67) argued that a stressor primarily leads to prolonged physiological activation when people have ruminative (ie, unintentional preservative) thoughts about the stressors. They further emphasized that the anticipation of future stressors is at least as important a determinant of prolonged physiological activation as are past stressful experiences, as accentuated in CATS (64). Hence Brosschot et al (67) considered "perseverative cognition", manifesting itself as rumination (about past stressors) and as anticipation (about potential future stressors) as an essential cognitive mediator of prolonged physiological activation. McEwen (16) also argued that such psychological states are likely to result in allostatic load because they stimulate the excretion of hormones like adrenaline (through activation of the SAM system) and cortisol (through activation of the HPA system).

Recent findings from laboratory research suggest that ruminative and anticipatory thoughts about stressors impede physiological recovery, whereas distraction contributes to it. For example, Glynn et al (68) showed that people who could ruminate after exposure to a stressful mental-arithmetic laboratory task showed delayed blood pressure recovery as compared with those who were prevented from ruminating as they were exposed to a nonstressful distractor task. Similarly, Neumann et al (69) demonstrated that distraction expedited cardiovascular recovery, probably by reducing rumination. Gaab et al (70) showed that participants' anticipatory cognitive (particularly threat and challenge) appraisals predicted their cortisol response to a standardized psychosocial stressor situation. Hall et al (71) demonstrated that stressful anticipatory thoughts about an oral speech that had to be delivered upon awakening in the morning had substantial prolonged physiological effects even during sleep.

Recent findings from field diary studies suggest that psychological detachment (ie, not thinking about work during off-job time) is associated with psychological recovery. Sonnentag & Bayer (72) showed that highly educated employees with various professional backgrounds who were able to detach psychologically from work during evening hours reported a more positive mood and less fatigue at bedtime than those who ruminated about work-related issues. Psychological detachment from work not only seems relevant during evening hours of regular workweeks, but also during longer respites (73). Fritz & Sonnentag (54) demonstrated that thinking negatively about one's job ("negative work reflection") during vacation was associated with increased feelings of exhaustion immediately and 2 weeks after the vacation period.

Indirect support for the assumption that cognitive processes may prolong physiological activation is provided by stress-intervention research. A meta-analytic review (74) revealed that particularly interventions aiming at physical and mental relaxation were effective in reducing physiological strain, as indicated by electromyographic activity and catecholamine levels.

The extent to which people are able to detach from work during off-job time seems to be related to work experiences. For example, an unpublished study of van Hooff and her colleagues among academics showed that those who expended high effort at work reported higher preoccupation with the upcoming workday during early morning hours than those who expended relatively low work-related effort. Sonnentag & Bayer (72) showed that participants reported greater difficulty to detach from their jobs at bedtime when they experienced chronic time pressure. [See also the paper by Sonnentag & Kruel (75).] Cropley & Millward Purvis (76) found that teachers in high-strain jobs ruminated more about their work during evening hours than teachers in low-strain jobs did. [For similar findings, see the paper by Grebner et al (77).]

In summary, there is evidence from various research approaches that cognitive processes such as the appraisal of coping options, rumination, and anticipation impede the recovery process by prolonging psychophysiological activation. In contrast, the ability to detach psychologically from work may facilitate the recovery process.

Concluding remarks

In this contribution we have provided a theoretical framework for arguing that recovery is a vital link between acute load reactions that are unavoidably associated with

effort expenditure at work, particularly under stressful conditions, and chronic health impairment. Load reactions are more likely to develop and spill over to the home domain in cases in which work conditions are very demanding or stressful and provide insufficient internal recovery opportunities. The spillover of load reactions increases the necessity for external recovery during after-work hours, during weekends, and during longer periods of respite (vacation). Recovery, a process of psychophysiological unwinding after effort expenditure, may occur through two complementary mechanisms, a "passive" mechanism reflecting a direct release from daily exposure to job stressors and a more "active" mechanism by a person's engagement in active leisure-time (eg, social, sport, or other physical) activities that have a recovering impact by, for instance, facilitating psychological detachment from work. Recovery during official off-job time may be impeded by prolonged exposure to work demands (working long hours), as well as by cognitive processes such as the appraisal of inadequate coping options and preservative worries about past or future stressors (rumination and anticipation, respectively). Both conditions prolong physiological activation and may result in "allostatic load", which is a crucial pathway between acute reactions to demanding or stressful work characteristics and chronic health impairment.

Suggestions for future research

We believe that this contribution complements current literature in this area by providing theoretical arguments and empirical support for the critical role of recovery in the transition between acute work-related load reactions and chronic ill health. Our contribution also raised the following questions that can be addressed in future research.

1. How do physiological and psychological recovery indicators relate to each other?

Although sustained activation (or incomplete recovery) may manifest itself physiologically (through, for instance, neuroendocrine and cardiovascular indicators) and psychologically (through subjective reports of, for instance, fatigue and recovery complaints), little is known about the interrelationship between these recovery indicators as they are strongly linked to different research approaches. [For notable exceptions, see the papers by Sluiter et al (17) and Kuiper et al (32).] Future research could benefit from a multimethod and multisource approach, including both physiological and psychological recovery indicators. [For critical evaluations, see the papers by Sonnentag & Fritz (31) and Semner et al (78).] Particularly the combination of these recovery indicators may provide insight into the dynamic interplay between the psychological and physiological processes involved in the transition of acute work-related load reactions to chronic health problems.

2. What are the long-term relations among exposure to workload, recovery and health?

Most studies on recovery have relied on cross-sectional designs or on designs with rather limited time frames [eg, 1 workweek (26, 51)]. Longitudinal studies covering larger time intervals are needed. [For notable exceptions, see the papers by van Hooff et al (18), Ganster et al (36), Stewart et al (37), Steptoe & Marmot (38), Kivimäki et al (39), and Gump & Matthews (40).] Important questions that could be addressed in these studies refer to the temporal lagged relationships among exposure to stressful work characteristics, recovery processes, and long-term health and well-being. This avenue of research may be particularly promising when both physiological and psychological indicators are included in order to study the recovery processes.

3. How does recovery unfold during longer periods of respite from work?

Most studies have focused on only short periods of respite from work, particularly during after-work hours in a regular workweek. However, weekends, and particularly vacations, may be—as relatively long periods of rest—more powerful opportunities to recover from work-related load effects. Future research on recovery during off-job time could benefit from addressing longer respites from work, as well as from addressing potentially recovering activities and experiences during such respites.

4. How do personality characteristics affect the recovery process?

Relevant, but as yet unanswered, questions are to what extent and how personality factors relate to the development of and recovery from work-related load reactions. Recent cross-sectional studies have shown positive associations of, for instance, neuroticism with fatigue and work–home spillover (79–81). These associations may indicate that anxious people perceive the same work characteristics as more stressful than others or have to mobilize more effort to conduct the same tasks. Both factors may increase the development and spillover of load reactions, which may become manifest in indicators of poor recovery. Personality factors may also be important regarding the stress-related cognitive processes discussed in this contribution. For instance,

anxious people may be more likely to have preseverative, ruminative, or anticipatory thoughts about stressors. Thus far, the relation between personality and recovery indicators has been studied by employing cross-sectional designs. Longitudinal studies covering longer time frames may provide more insight into whether recovery processes unfold differently for workers with different personality characteristics.

5. Under what conditions is recovery impeded by prolonged exposure to work demands?

Although extreme overtime work seems to be detrimental to a person's health in all circumstances, the impact of working moderately long hours may depend on work and personality characteristics (82). Recently, evidence has been provided that spending moderate overtime hours is associated with higher levels of fatigue and work–home spillover, but only in jobs characterized by high demands, low control, or low rewards (42, 60, 83). Moreover, also positive associations have been observed between moderate overtime work on one hand and work motivation and enjoyment on the other (41, 60). Future research on the impact of prolonged exposure to work demands on recovery could further investigate the possible moderating roles of work and personality characteristics, while taking into account the extent to which people work long hours.

6. Which nonwork activities contribute to or impede the recovery process, and through which underlying mechanisms do they act?

There are indications that active leisure-time activities may facilitate the recovery process. However, as yet, it is unclear exactly which (cognitive or physiological or both) mechanisms may play a role. It may be, for instance, that social or physical activities contribute to the recovery process through a cognitive process of distraction that enables people to detach from their work psychologically (68, 69). Moreover, there are indications that people who are more physically fit show more rapid cardiovascular recovery from stressors (84, 85), suggesting a physiological mechanism underlying the recovering effect of exercise. Hansen et al (86) provided evidence for a psychological effect of sports activities on well-being by showing that sport rapidly enhanced a person's mood. [See also the paper by Steinbert et al (87).] Future research may shed more light on the precise psychological or physiological mechanisms that underlie the recovering impact of active leisure-time activities. Obviously people also have to allocate their off-job time to activities with a somewhat obligatory nature (semi-leisure), such as household activities. As yet, engagement in household and care-giving activities has not been shown to have an unfavorable effect on recovery (26, 27), possibly because these activities may help workers to disengage from the daily strain of work (51). Alternatively, demands and obligations in the nonwork domain may cause strain themselves (88), impeding the recovery process during after-work hours. Indeed, recent research has shown that parents whose children are more ill felt that they performed more poorly at work because of more-limited recovery opportunities (89). Therefore, future research on effort and recovery should not only address activities, but also (stressful) experiences in both the work and nonwork domain. Conceptualizations of total workload (90) and multiple goal pursuit (91) may inspire this important area for future research.

7. Do stressful work characteristics and unhealthy lifestyles have an interactive effect on stress-related physiology and recovery processes?

Our contribution provides evidence that stress-related physiology plays a crucial mediating role in the link between exposure to stressful work characteristics and ill health. However, an even more important route to ill health may be via unhealthy behavior [eg, smoking, alcohol consumption, unhealthy diet, inactivity (66)]. This behavior may interact with the exposure to stressful work characteristics [eg, working long hours in high demanding jobs may elicit unhealthy lifestyles (13)] and may add to the burden on the physiological systems activated in the stress process (eg, elevated cortisol levels due to smoking and alcohol consumption). Future research could investigate the possible interactive and cumulative effect of repeated exposure to stressful work conditions and the use of unhealthy lifestyles on incomplete recovery and chronic health impairment.

8. Do intervention programs facilitate the recovery process?

There is increasing evidence that stress intervention programs improve psychological and physiological health (74, 92). Hereby, cognitive–behavioral interventions aiming at changing cognitions and reinforcing coping skills seem to be the most effective in reducing mental health complaints (eg, depression and anxiety), whereas relaxation techniques have proved to be valuable in reducing physiological strain [eg, catecholamine levels (74)]. To date, only a few intervention studies have included indicators of physiological recovery—as opposed to physiological reactivity—as potential outcome measures of the intervention program. In addition, interventions could aim at directly influencing recovery processes by instructing participants on how to use their work break in a "healthy way" (93), how to psychologically

detach from work during off-job time (94), and how to improve their sleep (95). These studies should not only look at short-term benefits such as decreases in ruminative thoughts or improved sleep quality, but also at longer term outcomes as they become obvious in objective health indicators.

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