Journal of Occupational Health Psychology
2003, Vol. 8, No. 4, 282–305

1076-8998/03/$12.00 DOI: 10.1037/1076-8998.8.4.282

"The *Very* Best of the Millennium": Longitudinal Research and the Demand-Control-(Support) Model

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This study addressed the methodological quality of longitudinal research examining R. Karasek and T. Theorell's (1990) demand-control-(support) model and reviewed the results of the best of this research. Five criteria for evaluating methodological quality were used: type of design, length of time lags, quality of measures, method of analysis, and nonresponse analysis. These criteria were applied to 45 longitudinal studies, of which 19 (42%) obtained acceptable scores on all criteria. These high-quality studies provided only modest support for the hypothesis that especially the combination of high demands and low control results in high job strain. However, good evidence was found for lagged causal effects of work characteristics, especially for self-reported health or well-being outcomes.

Karasek's (1979) demand-control (DC) model has been a leading work stress model in occupational health psychology since the 1980s. According to the model, a psychological work environment can be characterized by a combination of job demands and job control. Especially the combination of high job demands and low job control (high-strain jobs) is assumed to result in psychological stress reactions, such as high blood pressure and low job satisfaction. Conversely, low-strain jobs (characterized by low demands and high control) will lead to a lower than average number of health complaints (the *strain hypothesis*; Karasek, 1979; Karasek & Theorell, 1990). As Johnson and Hall (1988) had noted in previous research that support received from supervisors and colleagues often buffered the impact of demands and control on outcome variables, they proposed to extend the DC model with social support, resulting in the demand-control-support (DCS) model. The predictions of the DCS model strongly resemble those of the DC model, assuming that the strain hypothesis of the DC model will especially apply under conditions of low support.

A large body of research has tested the strain hypothesis. The results thereof did not always support the hypothesis (for reviews, see de Jonge & Kompier, 1997; Houtman et al., 1999; Kasl, 1996; Kristensen, 1996; Theorell & Karasek, 1996; Schnall, Landbergis, & Baker, 1994; van der Doef & Maes, 1999). For example, van der Doef and Maes's (1999) review showed that only 28 of 41 studies examining the relationship between job characteristics and psychological well-being supported the strain hypothesis. They reported comparable results for other outcomes. Van der Doef and Maes (1999) also reviewed the iso-strain hypothesis (the counterpart of the strain hypothesis in the DCS model) in 19 studies: Only 9 of these supported the association between the three job characteristics and psychological well-being.

Thus, it appears that the demand-control-(support) (or DC/S) model is not unequivocally supported. However, earlier reviews of the DC/S model suffered from several shortcomings that restrict the conclusions that can be drawn from these. First, they usually did not take the methodological quality of studies into account, which may bias the results (Kristensen, 1995). This may be an important reason for the inconsistent results presented in these reviews. It is possible that especially methodologically weak stud-

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ies failed to support the predictions of the DC/S model. For example, a high and selective nonresponse may result in restriction of range effects for both the independent and outcome variables, meaning that the magnitude of associations between these variables is underestimated (Taris, 2000).

A second limitation of earlier reviews is that they were primarily based on cross-sectional studies. For example, 53 of the 63 studies reviewed by van der Doef and Maes (1999) used a cross-sectional design. Such designs are ill-suited to test *causal* relationships, because they cannot provide any evidence regarding the temporal order of the variables. Although statistical techniques such as structural equation modeling (SEM) may provide an indication of the causal direction of particular pathways in cross-sectional research, strong evidence on the causal order of variables requires a longitudinal design (Cook & Campbell, 1979; Taris & Kompier, 2003). Further, cross-sectional designs do not allow for examining *reversed* and *reciprocal* causal relationships. In occupational health research it is often assumed that job characteristics (e.g., demands and control) influence health. Apart from these "standard" causal relationships, longitudinal designs often offer the possibility to examine the effects of Time 1 health on (the evaluation of) Time 2 job demands and control (reversed causal relationships; Zapf, Dormann, & Frese, 1996). This also implies that cross-sectional designs are ill-suited for exploring reciprocal causal relationships, in which variable X (e.g., job characteristics) and Y (e.g., health) mutually influence each other. Such relationships should be controlled for, as they may provide alternative explanations for certain associations between variables. Given the paucity of longitudinal studies in the reviews on the DC/S model, it seems fair to say that they provide little empirical material that supports causal interpretation of the associations among job demands, control, support, and health. Indeed, given the absence of studies examining reversed or reciprocal causal relationships at present, any such interpretation would seem mere speculation.

Finally, it is somewhat disquieting to note that earlier reviews did not clearly define which pattern of results is required to justify the conclusion that there is "a *joint* [italics added] effect of demands and control on outcomes measured over time" (Karasek, 1979, p. 287). Therefore, in the present review a definition of support of the strain hypothesis is proposed.

The present study aims to circumvent these limitations by (a) providing a definition of support of the strain hypothesis, (b) by examining high-quality longitudinal research on the DC/S model exclusively, and (c) by examining evidence for standard, reversed, and reciprocal causal relationships between work and health. By including only methodologically best studies, we intend to select the most reliable and valid results for inclusion in our review. By focusing on longitudinal research, we aim to provide an empirically sound basis for conclusions on the causal effects of job characteristics on health. Thus, this study aimed to provide a review of the results of the best longitudinal studies to date on the DC/S model, assuming that the material presented in these studies is exceptionally valuable in enhancing our understanding of the causal effects of job characteristics on worker health. Specifically, we deal with the following questions:

1. How many longitudinal studies examining the DC/S model meet five important methodological criteria and can therefore be labeled as *high-quality* studies?

2. What are the results of these high-quality longitudinal studies as regards the propositions advanced in the DC/S model? Moreover, do these high-quality studies provide evidence for normal (instead of reversed or reciprocal) "causal" relationships between Time 1 demands, control, or social support and Time 2 health outcomes?

When Is the Strain Hypothesis of the DC/S Model Supported?

One important issue that has as yet not been dealt with satisfactorily elsewhere concerns the issue when the strain hypothesis of the DC/S model is supported. Karasek (1989) stated that true (i.e., multiplicative) interaction effects are often difficult to detect because of lack of statistical power. He then argued that "the exact form of the interaction term is not the main issue, since the 'primary' interaction claimed in the model is that two separate sets of outcomes (strain and activity level) are jointly predicted by two different combinations of demands and control" (p. 143). Further, Karasek claimed that the practical implications for job redesign are similar for additive and interactive effects. This rather ambiguous formulation has generated some discussion whether the DC/S model is supported in the absence of significant multiplicative interaction terms of the DC/S dimensions: Do additive effects (i.e., main effects only) suffice (cf. de Jonge & Kompier, 1997; Kasl, 1996; Lands-

bergis, Schnall, Warren, Pickering, & Schwartz, 1994; Schnall et al., 1994; van der Doef & Maes, 1999)?

With Karasek, we consider focusing on the multiplicative interaction only too narrow. We therefore suggest that future research uses a broad definition of support of the DC/S model. In the present article we propose that both additive (main effects only) or multiplicative interaction effects support the strain hypothesis of the DC/S model, provided that workers in the high-demands/low-control condition experience the highest levels of strain. More specifically, we consider the strain hypothesis of the DC model supported when there are two main effects of job demands and job control *and*/*or* when there is a multiplicative interaction effect between these two work characteristics (not in combination with a third variable), such that employees working in environments characterized by high demands and low control experience the highest level of strain. The strain hypothesis of the DCS model is supported when the above-mentioned additive or multiplicative interaction effects of demands and control are complemented with a main or interaction effect of social support (not in combination with a fourth variable), such that employees working in environments characterized by high demands, low control, and low social support experience the highest level of strain.

Evaluation Criteria

Five criteria were applied to answer Research Question 1 concerning the methodological quality of longitudinal studies examining the DC/S model. Criteria were based on common insights from general and longitudinal research methodology, referring to (a) type of longitudinal design, (b) length of the time lags between the waves of the study, (c) quality of the measures, (d) statistical analysis, and (e) nonresponse analysis (e.g., Nesselroade & Baltes, 1979; Taris, 2000; Zapf et al., 1996).

Design

Figure 1 presents a complete panel design for two variables, X and Y (Zapf et al., 1996). In this design it is possible to examine cross-lagged effects (i.e., effects of variable X as measured on Time 1 on variable Y as measured on Time 2: for example, the effect of Time 1 demands on Time 2 health).

Cross-lagged effects cannot be interpreted causally unless four criteria have been satisfied (Cook & Campbell, 1979; Taris, 2000): (a) There is a statistically significant association between X and Y; (b) the causal variable X precedes the effect variable Y in time; (c) the association between X and Y is not due to third variables; and (d) there is a plausible theoretical argument for the relationship between X and Y. When a study uses a full panel design, three kinds of causal relationships can be examined. First, *normal* or *standard causal relationships* are hypothesized effects of, for instance, Time 1 demands on Time 2 fatigue. This is the type of effect that is usually examined in occupational health research. Second, *reversed causal relationships* run opposite to the hypothesized effects; for instance, fatigue may alter the perceptions of one's job demands across time (when fatigued, people may perceive their job demands as higher than when they are not fatigued). Finally, a study can examine *reciprocal causal relationships,* that is, whether (perceptions of) demands and fatigue mutually influence each other over time.

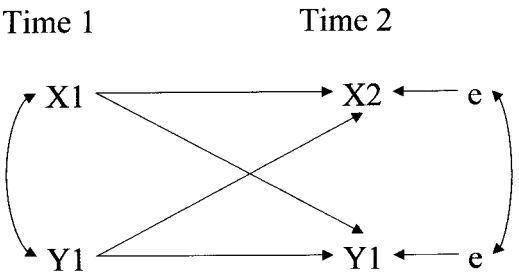

Figure 1. Complete panel design. X1 (X2) = variable X as measured on Time 1 (Time 2), Y1 (Y2) = measure of variable Y as measured on Time 1 (Time 2), e = measurement error.

The advantage of a complete panel design compared with incomplete panel designs (in which not all study variables are measured on all time points) is that these three types of causal relationships can be distinguished from each other, meaning that a fuller understanding of the causal process can be obtained. In practice, many studies use a panel design that includes measures of the independent and dependent variable on Time 1 and a measure of the dependent variable on Time 2. In this design only normal causal relationships can be tested; reverse or reciprocal effects cannot be examined (Zapf et al., 1996).

Time Lags

A complete panel design is insufficient to demonstrate causal effects of variables over time, because

the researcher still has to consider the length of the time lag that is needed to detect any effects. In general, there is little information available about the time lag that is needed for the causal variable to influence the effect variable (Taris & Kompier, 2003), and the recommendations concerning the length of this lag tend to be inconsistent. For example, whereas Zapf et al. (1996) preferred the same time lags when a study has more than two waves, Frese (1984) argued that when there are three or more measurements, some processes are better captured using time lags of different lengths. In the absence of commonly accepted guidelines on the correct length of time lags, researchers should discuss their choice for a particular time lag in the light of the question *how* the effect of X on Y develops over time (Frese & Zapf, 1988). Further, the choice for a particular time lag may also be based on the wish to control for alternative explanations for associations between variables, such as *interim effects* (i.e., effects of unobserved events during the time lag, such as a job change), *maturation effects* (e.g., effects due to increased experience), and *seasonal effects* (e.g., effects of measuring in summer or winter). In practice, the choice for a particular time lag is often motivated by the practical facilities of the research project or the time available to the researchers and the participants. However, such considerations should be complemented with plausible theoretical and methodological arguments.

Measures

Longitudinal research on the DC/S model usually used a survey design. Therefore, the reliability of the instruments measuring job characteristics and outcome variables is an important issue in this review. The reliability of an instrument can be demonstrated by referring to journal articles in which the quality of this instrument is established or by calculating a reliability score (such as Cronbach's alpha) for one's own data.

One important problem of using survey data only is the risk of self-report bias, for example, due to personality traits such as negative affectivity (Schnall et al., 1994). By combining subjective self-report measures with objective measures, researchers can mitigate the effects of methodological or conceptual overlap between the measured variables, thus reducing the risk of falling in the "triviality trap" (Kristensen, 1996). A study is considered acceptable when it includes good references for and acceptable reliabilities of one's variables (alpha of around .70; Stangor, 1998, p. 92); it is *very* good if it includes an objective measure as well (e.g., a psychophysiological measure), provided that this measure reflects a salient facet of the employees' experience.

Method of Analysis

Zapf et al. (1996) investigated 43 longitudinal studies and found that three main methods of statistical analysis were used: correlational research (e.g., the comparison of cross-lagged correlations), multiple regression, and structural equation modeling (SEM). Comparison of cross-lagged correlations may yield erroneous conclusions (Taris, 2000). In correlational research it is difficult to demonstrate reversed or reciprocal causal relationships, as the cross-lagged correlations depend on the variances of the measured variables (Zapf et al., 1996) and the across-time stability of the variables (Kessler & Greenberg, 1981). Therefore, multiple regression analysis and SEM are preferred for analyzing cross-lagged effects.

Nonresponse Analysis

When conducting research among a particular population, researchers should examine the nonresponse in their study. Possible selectivity of the response may be investigated on the first measurement when the research group is selected, but also on the follow-up responses. A study is considered acceptable when it examines possible selectivity of the response on baseline and on the follow-up measurements (e.g., in terms of gender and age); it is *very good* when it examines whether the associations at baseline between the DC/S dimensions and the outcome variables differ for responders and nonresponders (i.e., those who drop out of the study after baseline). This can be achieved by exploring the association between work and health at baseline for the response group versus the group that drops out after baseline.

Evaluation Criteria

On the basis of these considerations, a system was developed to rate the methodological quality of studies (see Table 1 for a summary). In principle, studies could obtain 1 star (*insufficient*) to 4 stars (*very good*) for each criterion. As regards method of analysis, however, studies received either 1 star (*insufficient*) or 3 stars (*good*), referring to the distinction between correlational research and multiple regression/SEM, respectively.

One important aspect of longitudinal research is

Table 1
Criteria for Evaluating the Quality of Longitudinal Research

Criteria	*1 star (*insufficient*)	**2 stars (*sufficient*)	***3 stars (*good*)	****4 stars (*very good*)
Design	At least one variable not measured on all occasions	At least one variable not measured on some occasions (incomplete panel design)	All variables measured twice (complete panel design)	All variables are measured more than twice (complete panel design with >2 measurements)
Time lags	1 time lag and no argument	>1 and no argument	1 time lag and a theoretical and/or methodological argument	>1 time lag and a theoretical and/or methodological argument
Measures	Insufficient or questionable information	Good references	Good references and good psychometric checks on own data	Good references and good psychometric checks on own data and at least 1 “objective” indicator
Method of analysis	Correlational research		SEM (structural equation modeling) and/or multiple regression	
Nonresponse analysis	No check on selectivity of the sample	Check on selective Time 1 response or check on selective panel or follow-up response	Check on selective Time 1 response *and* check on selective panel or follow-up response	Check on selective Time 1 response *and* check on selective panel or follow-up response, and further research of the differences between the response and the nonresponse group concerning the hypotheses of the study

the number of measurements of a study. More measurements result in more information about the variables and the relationships among these over time, meaning that the quality of a study increases with the number of measurements. This is reflected in the allotment of stars on the two criteria, design and time lags.

Method

Study Selection

We define *study* as any publication containing longitudinal research examining the DC/S model. Longitudinal studies examining the DC/S model were identified through a systematic database search. As Karasek first introduced the DC model in 1979, this year was chosen as our starting point. The databases searched were Medline (1979 to 1999), PsycINFO (1979 to 1999), and the Social Science Citation Index (1988 to 2000; material published before 1988 could not be searched through Internet in this database). Various combinations of the following keywords were used: *job demands, control, support, skill discretion, longitudinal, (job) DC/S model,* and *job strain*. After retrieving the longitudinal studies located in this vein, we inspected the references to these studies to track down other longitudinal studies on the DC/S model that had not yet been included. Furthermore, several internationally acknowledged experts working with the DC/S model were contacted through e-mail. They provided longitudinal studies for inclusion in our review as well.

To be included, studies had to meet the following criteria: (a) The study was based on two or more waves of data; (b) the study was based on the DC or DCS model; (c) the dimensions of the DC/S model were measured by questionnaire; (d) the study was published either before or in 2000. No restrictions were imposed regarding the type of outcome variable. In this vein, 45 longitudinal studies on the DC/S model were identified (these 45 articles are included in the list of references to the present study, preceded by an asterisk). Note that some studies were based on partly the same data set (this applies to Bosma et al., 1997, Bosma, Peter, Siegrist, & Marmot, 1998; Carayon, 1992, 1993; Stansfeld, Bosma, Hemingway, & Marmot, 1998; Stansfeld, Fuhrer, Head, Ferrie, & Shipley, 1997; Stansfeld, Fuhrer, Shipley, & Marmot, 1999). As these studies were based on different end-points or different research questions (i.e., they presented different parts of the same underlying data set), they were evaluated separately.

Author Ratings

All 45 studies were rated by de Lange using the rating scheme presented in Table 1. To obtain an impression of the reliability of this rating, we contacted the 39 first authors of the 45 studies by surface mail. Note that some authors published two or more relevant studies in which partly the same data set was analyzed (e.g., the outcome variable differed across studies). These studies were considered independently. They received a letter explaining the aim of our study, our assessment of their study, an extended ver-

sion of the rating scheme presented in Table 1, and an answer sheet. We felt that providing authors with our rating of their work might influence the response rate negatively. Therefore, they did not receive our judgment of their quality of their study but rather the *facts* reported in their study. For example, for "Number of measurements," we mentioned the number of waves of the study; for "Statistical analysis," the method of analyzing the data was mentioned; and so on. The authors were asked whether they agreed with our judgment; if not, they were asked what they felt was correct, as well as why they felt that our judgment was incorrect.

After 2 months, 23 completed questionnaires (a 58.9% response rate) had been returned. Nonresponse analysis revealed that our ratings of the studies corresponding with these 23 authors did not differ significantly from our ratings of the studies authored by the nonresponders. Thus, there was no reason to assume that the response was biased. In 7 cases (30%) the authors fully agreed with our judgment. In the other cases authors either felt that our judgments were not (entirely) correct or provided more information about their study. In all cases their comments were checked by de Lange and Taris. As might be expected, the general purport of these reactions was that our ratings were too negative. One quite typical reaction was that we were correct in noting that a particular study did not report information about the reliability of the measures used but that the relevant information could be found in other publications or reports. If so (and if the reliability of these measures was acceptable), our ratings of these studies were amended accordingly.

The authors commented in 29 cases on our evaluation of particular aspects of their study. In 7 cases, these comments led to a minor change in our rating. As each study was rated on five criteria, this figure implies that of the total ($23 \times 5 =$) 115 ratings that were checked by the authors, ($100 - 29/115 =$) 74.8% was accepted as correct.

Results

Description of the 45 Studies

Table 2 presents information on the 45 longitudinal studies examining the DC/S model. This table presents detailed information concerning the homogeneity/heterogeneity of the population under study, the model tested (DC or DCS model), the measurement of the DC/S dimensions, the outcome type, and the type of confounders that was controlled (if any).

Population. The nature and size of a research population may have important implications for the results of a study (de Jonge & Kompier, 1997). Specifically, the research population should present enough variation on the DC/S dimensions. Kristensen (1995) even argued that the amount of variation is more important than the representativeness of the sample under study. As heterogeneous populations (i.e., populations including more than one job category) present more variation or exposure contrast in work characteristics than homogeneous populations (including participants with the same jobs), heterogeneous populations may be considered as more useful for testing the effects of (combinations of) job characteristics. Table 2 shows that 33 of the 45 studies selected for this review (73%) used heterogeneous samples.

DC versus DC/S model. Contrary to earlier reviews (e.g., van der Doef & Maes, 1999), the studies selected in this review examined the DCS model more often than the DC model: 34 out of 45 studies (76%) used the DCS model.

Measurement of DC/S dimensions. Psychosocial work characteristics can be measured at the level of the individual participants (e.g., using self-report questionnaires) or at the job level (by imputing values for the job characteristics; Landsbergis & Theorell, 2000). In the latter strategy, occupation codes provided by the participants are used to estimate the levels of job demands, control, and support that are typical for their jobs (e.g., based on expert judgments). Thus, all individuals in a particular occupation receive the same scores on the work characteristics; individual (error) variability between participants is thus discarded, at the cost of discarding true individual and within-occupation variation in job characteristics as well. Table 2 shows that 6 of our 45 studies (13%) used the imputation method. Almost half (53%) of the studies using self-report questionnaires employed Karasek et al.'s (1998) Job Content Questionnaire (JCQ) or JCQ-based items. In the remaining cases less well-known instruments were used.

Outcome type. The 45 studies selected for this review used many different outcome variables. These were grouped in six categories: (a) self-report measures for health or well-being, (b) sickness absence measures, (c) cardiovascular measures; (d) other physiological measures, (e) lifestyle factors; and (f) other outcomes (such as "risk scores" based on different types of outcome variables, and externally determined psychotic disorders).

Table 2 shows that the majority of the studies (51%, 23 studies) examined self-report measures for health or well-being (mostly indicators of psychological distress). In addition, 6 studies (13%) examined sickness absence, 12 studies (27%) examined indicators of cardiovascular disease, 4 studies (9%) focused on other physiological strain-related measures, 4 studies (9%) examined lifestyle factors, and 3 studies (7%) examined other outcome measures such as externally determined psychotic disorders. Note that

(*text continues on page 292*)

Table 2
Information on 45 Selected Longitudinal Studies

Study	Population	DC or DCS model	Measurement of DC/S	Outcome type	Type of confounders
Barnett and Brennan (1997)	**He:** 504 full-time employed ♀, ♂ (couples from 2 Boston-area towns)	DCS	Job Experience scale	**1** Psychological distress	A, B
Bosma et al. (1997)	**He:** 6,895 ♂ (67%), 3,413 ♀ (33%) civil servants from 20 London-based civil service departments	DCS	JCQ	**3** New cases of angina, severe pain across the chest, diagnosed ischaemic heart disease, any coronary event	A, B, D
Bosma et al. (1998)	**He:** 6,895 ♂ (67%), 3,413 ♀ (33%) civil servants from 20 London-based civil service departments	DCS	JCQ	**3** New cases of angina, severe pain across the chest, diagnosed ischaemic heart disease, any coronary event	A, B, D
Bourbonnais et al. (1999)	**Ho:** ♀ 1,741 nurses in 6 hospitals in Quebec, Canada	DCS	JCQ	**1** Psychological distress and burnout	A, B, D
Bromet et al. (1988)	**He:** 325 nonmanagerial ♂ employees of 2 nuclear power plants and 2 generating plants in Pennsylvania	DCS	Occupational stress scales Social support (Moos, 1981)	**5** Alcohol-related problems **6** Interview determined diagnosable episodes of depression, anxiety, symptoms, Symptom Checklist-90	A, D
Carayon (1992)	**He:** 122 office workers (70% ♀, 30% ♂) from a midwestern public service organization	DCS (1992)	Scales from several sources (not JCQ)	**1** Indicators of worker strain	A
Carayon (1993)	**He:** 122 office workers (70% ♀, 30% ♂) from a midwestern public service organization	DC (1993)	Scales from several sources (not JCQ)	**1** Indicators of worker strain	A
Chapman et al. (1990)	**He:** 534 ♀, 2,100 ♂ Australian government employees working in Sydney (♂ from 8 diverse occupations, ♀ from 2 occupations)	DCS	Work-response questionnaire (items from several sources)	**3** Blood pressure	C, D
Cheng et al. (2000)	**Ho:** Ongoing cohort of 21,290 registered ♀ nurses in the U.S.	DCS	JCQ	**1** Indicators of subjective health	A, C, D
Crum et al. (1995)	**He:** 126 (72.2% ♂ and 27.8% ♀) incident cases and 381 age- and residence-related; matched noncases from household residents in five metropolitan areas (different occupations)	DCS	Imputation method	**5** Alcohol abuse; determined in an interview; using data from Diagnostic Interview Schedule	A, D
Daniels and Guppy (1994)	**Ho:** 244 (86.1% ♂, 13.9% ♀) British accountants	DCS	Job/organizational characteristics, support and stressors scale	**1** Psychological well-being	D
de Jonge et al. (1998)	**Ho:** 261 (87% ♀, 13% ♀) nurses and caregivers	DCS	Maastricht Autonomy Questionnaire Work pressure scale Social support scale	**1** Burnout and job satisfaction	

Table 2 (*continued*)

Study	Population	DC or DCS model	Measurement of DC/S	Outcome type	Type of confounders
Dollard (1997)	**Ho:** 107 nurses (99 ♀, 8 ♀) employed in a medium-sized public hospital in rural Australia	DCS	Work Environment Scale	**1** Indicators of health, work–home conflict and job satisfaction	A, B, C, D
Fenwick and Tausig (1994)	**He:** 830 American workers (29% ♀, 71% ♂; different occupations)	DCS	JCQ	**1** Life satisfaction and indicators of stress: psychophysiological symptoms associated with anxiety	A, D
Furda et al. (1994)	**Ho:** 115 Dutch employees (32.3% ♀, 67.7% ♂) working in an insurance company (administrative functions)	DCS	JCQ	**1** Subjective health and recovery complaints	A
Hammar et al. (1998)	**He:** 10,008 Swedish cases (8,833 ♂, 1,175 ♀) of first myocardial infarction and 28,448 (24,913 ♂, 3,535 ♀) controls (different occupations)	DCS	Imputation method: Work organization exposure matrix	**3** Myocardial infarction	A, D
Hjollund et al. (1998)	**He:** 430 (♀, ♂) couples (childless, wish for child; different occupations)	DCS	JCQ	**4** Fertility	A, D
Johnson et al. (1995)	**Ho:** 495 (♀, ♂) graduates, working as physician	DCS	JCQ (adapted to physicians)	**1** Indicators of psychiatric distress, job dissatisfaction	A
Johnson et al. (1989)	**He:** 7,219 ♂ employed Swedish (blue-, white-collar workers, different occupations)	DCS	Swedish questionnaire measuring items relating to work	**3** The prevalence of cardiovascular disease morbidity and cardiovascular-specific mortality	A
Johnson and Stewart (1993)	**He:** 12,084 employed Swedish citizens (46.8% ♀, 53.2% ♂)	DCS	Scales and imputation method (job exposure matrix)	**1** Subjective health: 1 or more subset of illnesses with a plausible stress-related etiology	A, D
Karasek (1979)	**He:** 950 Swedish employed ♂	DCS	JCQ	**1** Indicators of mental strain	A, D
Karasek et al. (1981)	**He:** 1,461 Swedish employed ♂	DCS	JCQ	**3** Cardiovascular disease	A, C, D
Kivimäki et al. (2000)	**He:** 764 (189 ♂, 575 ♀) Finnish municipal employees who remained in employment after downsizing (blue- and white-collar workers; different occupations)	DCS	Items based on JCQ	**2** Certified sickness absence	A, C, D
Landsbergis and Hatch (1996)	**He:** 717 ♀ workers (from Pennsylvania and New York; predominantly middle class; different occupations)	DCS	11 questions on psychosocial characteristics (comparable with JCQ; items in Appendix of article)	**3** Pregnancy-induced hypertension	A, D
Landsbergis et al. (1998)	**He:** 202 employed American ♂ (different occupations)	DC	JCQ	**5** Cardiovascular disease-related health behaviors: e.g., cigarette smoking, alcohol use, lack of exercise	A, D

(*table continues*)

Table 2 (*continued*)

Study	Population	DC or DCS model	Measurement of DC/S	Outcome type	Type of confounders
Muntaner et al. (1991)	**He:** 11,789 (♂, ♀) American household residents (blue- and white-collar workers; 2 different occupations)	DCS	Imputation method (based on 3 national surveys on employment conditions conducted by the Department of Labor	**6** Psychotic disorders diagnosed by interviewers	A, C, D
Noor (1995)	**He:** 180 English ♀ working who were solicited from 2 occupational groups	DC	Work overload and autonomy scales	**1** Measure of positive affect (Happiness) and of psychological distress (GHQ)	A, B, D
Parkes (1982)	**Ho:** 164 student nurses (♂, ♀) British or Irish	DCS	Questionnaire based on DC model Work environment scale	**1** Indicators of psychological distress: somatic symptoms, depression, anxiety, social dysfunction, work satisfaction **2** Noncertificated sickness absence spells	A, D
Parkes (1991)	**Ho:** 264 (93 ♂, 171 ♀) graduates taking a 1-year course leading to a teaching qualification	DC	Questionnaire based on JCQ	**1** Indicators of mental health: anxiety, social dysfunction	A
Parkes et al. (1994)	**Ho:** 264 (93 ♂, 171 ♀) graduates taking a 1-year course leading to a teaching qualification	DCS	Questionnaire based on JCQ	**1** Indicators of somatic symptoms	A, B
Pollard et al. (1996)	**He:** 104 workers (51 ♂, 53 ♀); recruited from the general population (different occupations)	DC	Scales from other resource than JCQ	**1** Indicator of mood **4** Hormones	C, D
Reed et al. (1989)	**He:** 8,006 ♂ of Japanese ancestry in Hawaii (different occupations)	DC	Imputation method (using occupation scores of the 1970 U.S. Census Occupation)	**3** Incidence of coronary heart disease	A, C, D
Riese et al. (2000)	**Ho:** 165 ♀ nurses (from 3 nonacademic hospitals in Amsterdam, the Netherlands)	DCS	JCQ	**3** Risk indicators of cardiovascular disease	A, C, D
Schnall et al. (1998)	**He:** 195 American ♂ (different occupations, white-collar workers overrepresented)	DC	JCQ	**3** Ambulatory blood pressure	A, B, C, D
Smulders and Nijhuis (1999)	**He:** 1,755 ♂ employees of a technical maintenance firm in the public sector (the Netherlands)	DC	Questionnaire measuring psychosocial characteristics	**2** Registered sickness absence rate and frequency	A, D
Stansfeld et al. (1998)	**He:** 10,308 British (♀, ♂) civil servants	DCS	JCQ Social Support: Close Persons Questionnaire	**1** Indicators of physical, emotional, and social functioning	A, B, C, D

Table 2 (*continued*)

Study	Population	DC or DCS model	Measurement of DC/S	Outcome type	Type of confounders
Stansfeld et al. (1997)	**He:** 6,895 ♂ and 4,313 ♀ (11,208) London-based civil servants	DCS	JCQ	**1** Indicators of psychological distress (GHQ) **2** Computerized sickness absence records	A, C, D
Stansfeld et al. (1999)	**He:** 6,895 ♂ and 4,313 ♀ (11,208) London-based civil servants	DCS	JCQ	**1** Indicators of psychological distress (GHQ)	A, D
Steenland et al. (1997)	**He:** 3,575 ♂ and 519 heart disease cases (NHANES1; blue- and white-collar workers; different occupations)	DC	Imputation method	**3** Heart disease	A, C, D
Steptoe et al. (1998)	**He:** 71 workers (44 ♀, 27 ♂) in the retail industry (mostly working in sales departments, some in distribution)	DCS	JCQ	**1** Indicators of well-being, job satisfaction and work–home interference **4** Cortisol **5** Smoking and alcohol consumption	A, C
Theorell et al. (1990)	**He:** 44 working ♂ from 6 different occupations (blue- and white-collar workers)	DC	Items based on JCQ	**4** Plasma testosterone fluctuations	A, C, D
Vahtera et al. (2000)	**He:** 530 municipal Finnish workers (138 ♂, 392 ♀; blue- and white-collar workers; different occupations)	DCS	Items based on JCQ	**2** Medically certified sickness absence rates	A, C, D
Vahtera et al. (1996)	**He:** 856 (♀, ♂) Finnish municipal employees (blue- and white-collar workers; different occupations)	DCS	Items based on JCQ (questions from 2 Finnish studies)	**2** Medically certified sickness absence spells	A, D
van der Doef and Maes (2000)	**Ho:** 369 nurses (85% ♀, 15% ♂) from 7 nursing homes	DCS	Leiden Quality of Work questionnaire	**1** Psychological distress **6** Cardiovascular Risk Score: based on, e.g., gender, age, smoking status, blood sample analysis of serum cholesterol	A, D
van Egeren (1992)	**He:** 37 employees with sedentary jobs at the Michigan State University (20 ♀, 17 ♂; different occupations)	DC	JCQ	**3** Blood pressure	A, B, D

Note. More detailed information about these 45 studies can be obtained from Annet H. de Lange. **He** = heterogeneous (when the study was based on >1 type of occupation; independent of the type of position within the occupation); **Ho** = homogeneous (when the study was based on 1 type of occupation; position within the occupation not considered). Type of dependent measure: **1** = self-report measures for health and/or well-being; **2** = sickness absence measures; **3** = cardiovascular measures; **4** = other physiological measures; **5** = lifestyle factors; **6** = other measures (such as risk score based on different types of dependent outcomes; externally determined psychotic disorders, etc.). Type of confounder: A = demographic variables (age, gender, etc.); B = personality characteristics (hostility, negative affectivity); C = lifestyle factors (such as smoking behavior and alcohol consumption); D = other factors (e.g., earlier health complaints, family history, relevant physiological control measures). DC = demand-control model; DCS = demand-control-support model; JCQ = Job Content Questionnaire; GHQ = General Health Questionnaire; NHANES1 = First National Health and Nutrition Examination Survey. ♀ = women; ♂ = men.

these percentages do not add up to 100%, as studies could explore more than one type of outcome.

Confounders. Generally speaking, in determining the causal relationship between work and health, it is important to control for alternative explanations (especially when examining categorical outcomes; see Schnall et al., 1994). Table 2 shows that the studies included in this review controlled for various types of possible confounders, mostly for (a) demographic variables (age, gender, and the like; these were controlled for in 41 studies); but also for (b) personality characteristics (e.g., hostility, negative affectivity; these were controlled for in 10 studies); (c) lifestyle factors (such as smoking behavior and alcohol consumption; these were controlled for in 16 studies); and (d) other factors (earlier health complaints, family history, relevant physiological control measures; these were controlled for in 35 studies).

Related to outcome type, Table 2 shows that the 45 studies did not consistently control for the same number and type of confounders. For instance, of the 23 studies examining self-report measures for health and well-being, most (20 studies) controlled for demographic variables, but some studies also controlled for personality characteristics (6 studies), lifestyle factors (6 studies), and other factors (13 studies). The same applies to the 12 studies examining cardiovascular measures, of which most studies (11 studies) controlled for demographic variables, but some studies also controlled for personality characteristics (4 studies), lifestyle factors (6 studies), and other factors (10 studies).

Although it is generally desirable to control for possible confounders, it is for several reasons unclear how inclusion of various types of control variables should be evaluated in this review. First, it would seem that in some cases the distinction between control variable and variable of substantive interest is blurred. For instance, the cluster of lifestyle factors includes control variables that may equally well serve as outcomes, next to the variables of interest in these studies (such as alcohol-related problems). Second, it is often hard to decide whether inclusion of a specific control variable is necessary to obtain an unbiased estimate of a particular effect. Whether a researcher should control for a particular variable depends strongly on the process under study; but as the precise nature of this process is often largely unknown, it is also difficult to decide *which* variables should be controlled for. Inclusion of control variables is not a matter that should be taken lightly; for example, whereas some authors recommend controlling for differences in negative affectivity as a matter of routine, others strongly argue against inclusion of this concept as this would lead to an underestimation of the magnitude of the effects of interest (Karasek et al., 1998; Spector, Zapf, Chen, & Frese, 2000). Thus, "better safe than sorry" does not apply here. Finally, it is often argued that the bias resulting from confounders is relatively limited in longitudinal research, as participants act as their own controls (Taris, 2000). If this is true, there is no reason to discount studies because they do not include any control variables. For these reasons we decided not to judge the methodological quality of the 45 studies included in the present research in terms of the presence versus the absence of control variables.

Evaluation of the Quality of the 45 Studies

Table 3 presents our evaluation of the 45 studies on the basis of the evaluation criteria shown in Table 1. The number of stars per criterion varied across studies, except for method of analysis.

Design. One study (Riese, van Doornen, Houtman, & De Geus, 2000) was evaluated as *insufficient*, because it did not measure the dependent and independent variable at the same point in time. As a result, cross-lagged effects could not be examined. In 19 studies (42%) an incomplete panel design was used, as some of the research variables were not measured at all occasions: therefore, these studies were rated as *sufficient*. A complete panel design was used in 25 studies (53%). Sixteen of these included two measurements (these were evaluated as *good*), whereas 9 studies included more than two measurements (*very good*).

Time lags. Table 3 shows that 26 studies used a two-wave design, whereas 19 studies included three to six measurements. The time lags between the measurements of all 45 studies varied between approximately 28 days (Hjollund et al., 1998, Study 18) to 12 years (Steenland, Johnson, & Nowlin, 1997, Study 41). Seventeen of these 45 studies (38%) failed to present a theoretical or methodological argument for the time lag used. These studies were rated as *insufficient* on this criterion. Fifteen studies used more than two measurements and were evaluated as *sufficient*. Two 2-wave studies provided a satisfactory argument for their time lags used and were evaluated as *good*. Daniels and Guppy (1994) used a 1-month time lag, based on earlier research examining the relationship between social support and control. De Jonge, Le Blanc, Schaufeli, and van der Linden (1998) used a 1-year time lag to measure indicators of psychological distress based on the re-

Table 3
Evaluation of 45 Longitudinal Studies on the DC/S Model

Study	No. of measurements	Design	Time lag	Measure	Nonresponse analysis
Barnett and Brennan (1997)[a]	3	****	**	**	**
Bosma et al. (1997)[a]	3	****	**	****	***
Bosma et al. (1998)[a]	3	****	**	****	***
Bourbonnais et al. (1999)[a]	2	***	**	***	****
Bromet et al. (1988)[a]	2	**	**	**	***
Carayon (1992)[a]	2	***	**	***	**
Carayon (1993)[a]	2	***	**	***	***
Chapman et al. (1990)[a]	3	****	**	**	**
Cheng et al. (2000)	2	***	*	**	**
Crum et al. (1995)	2	**	*	**	***
Daniels and Guppy (1994)[a]	2	**	***	***	***
de Jonge et al. (1998)[a]	2	***	***	**	**
Dollard (1997)[a]	2	**	**	****	****
Fenwick and Tausig (1994)	2	***	*	**	**
Furda et al. (1994)	2	***	*	***	*
Hammar et al. (1998)	2	***	*	**	**
Hjollund et al. (1998)[a]	6	**	****	**	**
Johnson et al. (1995)[a]	2	**	**	***	**
Johnson et al. (1989)	2	***	*	**	*
Johnson and Stewart (1993)	2	**	*	**	**
Karasek (1979)	2	***	*	***	**
Karasek et al. (1981)	2	***	*	**	**
Kivimäki et al. (2000)	3	**	****	****	*
Landsbergis and Hatch (1996)	3	**	**	****	**
Landsbergis et al. (1998)	2	***	*	****	**
Muntaner et al. (1991)	2	**	*	**	*
Noor (1995)	2	***	*	**	*
Parkes (1982)[a]	5	**	**	****	**
Parkes (1991)[a]	3	**	**	***	***
Parkes et al. (1994)[a]	2	**	**	***	***
Pollard et al. (1996)	3	****	****	****	*
Reed et al. (1989)	3	**	**	**	*
Riese et al. (2000)	2	*	*	**	**
Schnall et al. (1998)	2	***	*	****	**
Smulders and Nijhuis (1999)	4	**	**	****	*
Stansfeld et al. (1998)	3	****	**	***	*
Stansfeld et al. (1997)	3	****	**	**	*
Stansfeld et al. (1999)	3	****	**	***	*
Steenland et al. (1997)	2	**	*	**	*
Steptoe et al. (1998)[a]	4	**	**	****	**
Theorell et al. (1990)	4	****	****	****	*
Vahtera et al. (2000)[a]	3	**	****	****	**
Vahtera et al. (1996)	2	***	*	****	**
van der Doef and Maes (2000)	2	***	**	****	*
van Egeren (1992)	4	**	**	**	*

Note. * = *insufficient,* ** = *sufficient,* *** = *good,* **** = *very good.* The results for method of analysis are not included as all studies were evaluated as "good."
[a] These studies were judged as at least "sufficient" on all five criteria and were thus considered high-quality studies.

sults of a pilot study that recommended this time lag to control for seasonal effects. Six other two-wave studies also used a 1-year time lag to predict effects of the DC/S dimensions on psychological distress (Bourbonnais, Comeau, & Vezina, 1999; Bromet, Dew, Parkinson, & Schulberg, 1988; Carayon, 1992, 1993; Dollard, 1997; Johnson et al., 1995), but these failed to provide an argument for this particular lag and were therefore revalued as *sufficient* (instead of *insufficient*).

Five multiwave studies (Hjollund et al., 1998; Kivimäki, Vahtera, Pentti, & Ferrie, 2000; Pollard, Ungpakorn, Harrison, & Parkes, 1996; Theorell, Karasek, & Eneroth, 1990; Vahtera, Kivimäki, Pentti, & Theorell, 2000) were rated as *very good*. Hjollund et al. (1998) examined the relationship between high demands, low control, and fertility of women and measured these variables on two to six occasions. Their time lag was based on the length of the menstrual cycle (with a maximum of six cycles) and may thus vary between and within participants. The three-wave studies by Kivimäki et al. (2000) and Vahtera et al. (2000) addressed the effects of downsizing on employee health. The time lags of 3 and 2 years (Kivimäki et al., 2000) and 3 and 4 years (Vahtera et al., 2000) were based on the timing of the organizational interventions: The questionnaires were sent out before, during, and after downsizing. Pollard et al. (1996) examined the effects of the DC dimensions on epinephrine and cortisol levels over time, using two 1-day time lags to compare working days with rest days (Sunday). Further, they based the time lag for measuring hormones on results of earlier research that showed that urinary excretion rates of epinephrine reflects plasma levels within 1 hr. Theorell et al. (1990) examined the relationship between DC dimensions and plasma testosterone fluctuations over time. They used three 3-month periods between their measurements, arguing that this time lag avoids group effects as a result of seasonal variation.

Measures used. No studies were considered *insufficient* on this criterion. Nineteen studies (42%) presented good references for their measures but did not provide psychometric checks or provided unsatisfactory results for their measures (e.g., Cronbach's alphas $<$ .70). They were therefore evaluated as *sufficient*. Eleven studies (24%) presented both good references for the measures used and acceptable psychometric checks. These studies were rated as *good*. Finally, 15 studies (33%) not only presented good references and psychometric checks but included an objectively measured indicator as well. These studies were evaluated as *very good*.

Method of analysis. Little variation was found on this criterion: All studies were evaluated as *good*. Multiple regression analysis was used in 43 studies; 2 studies (Barnett & Brennan, 1997; Fenwick & Tausig, 1994) used SEM.

Nonresponse analysis. Fifteen studies (33%) did not sufficiently examine possible response bias on the first and the follow-up measurements. Twenty studies (44%) examined possible response bias on at least one of the measurements of the study (the first or follow-up). Eight studies (18%) were evaluated as *good*, because they explored the selectivity of the response on the first measurement as well as on the follow-up wave. Bourbonnais et al. (1999) and Dollard (1997) were evaluated as *very good*, because these studies presented an elaborate discussion of possible selective response and dropout.

High-Quality Studies and Their Results

What are the high-quality studies? Our first research question concerned the identification of high-quality longitudinal studies. The 45 studies were divided in two categories using what might be called a *multiple-hurdle* approach (with the hurdles corresponding with the five evaluation criteria). To be considered a *high-quality* study, studies had to obtain at least *sufficient* scores on all five criteria (19 studies, or 42%). This procedure is based on the reasoning that the magnitude of the effects presented in the less reliable studies might be over- or underestimated as a result of different forms of bias. Thus, this procedure maximizes the reliability of the results presented in the high-quality studies.

What are the results of the high-quality studies? Table 4 presents a detailed breakdown of the findings reported in the 19 high-quality studies. The results of these studies are first discussed per type of outcome variable. Next, we discuss whether the results provide support for the strain hypothesis of the DC or DCS model. Following Greenland (1998), if a study reports significant main effects of demands and control as well as a Demand $\times$ Control interaction effect, we will only interpret the interaction effect. Further, as this study focuses on the effects of the dimensions of the DC/S model, Table 4 does not present possible interactions with other variables.

Self-report measures for health or well-being. Twelve high-quality studies (63%) examined self-report measures for health or well-being (mostly indicators of psychological distress). Three of these (Barnett & Brennan, 1997; Bourbonnais et al., 1999; Parkes, 1982) reported main effects of both demands and control in predicting indicators of psychological well-being over time (confirming the strain hypothesis of the DC model). Next to main effects of demands and control, Bourbonnais et al. (1999) and Parkes (1982) reported main effects of social support in predicting the outcome variables as well.

Parkes, Mendham, and von Rabenau (1994) and Dollard (1997) reported significant multiplicative Demand $\times$ Control interaction effects in predicting

(*text continues on page 298*)

Table 4
Overview of the Results of 19 High-Quality Studies

Study	Population	Dependent variable(s)	Effects of DC/S dimension	Support strain hypothesis DC and/or DCS model	Time lag(s)	Evidence causation
Barnett and Brennan (1997)	**He:** 504 full-time employed ♀, ♂ (couples from 2 Boston-area towns)	1 Psychological distress	D^s, C^s ("skill discretion"), (S)	DC	2 of 1 year (**)	A: + B: n.e.
Bosma et al. (1997)	**He:** 6,895 ♂ (67%), 3,413 ♀ (33%) civil servants from 20 London-based civil service departments	3 New cases of angina, severe pain across the chest, diagnosed ischaemic heart disease, any coronary event	(D), C^s, (S)	X	2 of which mean length of follow-up: 5.3 years (**)	A: + B: n.e.
Bosma et al. (1998)	**He:** 6,895 ♂ (67%), 3,413 ♀ (33%) civil servants from 20 London-based civil service departments	3 New cases of angina, severe pain across the chest, diagnosed ischaemic heart disease, any coronary event	(D), C^s, (S)	X	2 of which mean length of follow-up: 5.3 years (**)	A: + B: n.e.
Bourbonnais et al. (1999)	**Ho:** ♀ 1,741 nurses in six hospitals in Quebec, Canada	1 Psychological distress and burnout		DC, DCS		A: + B: n.e.
		Psychological distress	D^s, C^s, S^s		1 of approximately 1 year (**)	
		Burnout	D^s, C^s, S^s		1 year (**)	
Bromet et al. (1988)	**He:** 325 Nonmanagerial employees of 2 nuclear power plants and 2 generating plants in Pennsylvania	5 Alcohol-related problems	(D), C^s, (S), D × C^s	DC	1 time lag of 1 year (**)	A: + B: n.e.
		6 Interview determined: Diagnosable episodes of depression, anxiety	D^s, (C), (S) (D × C), D × S^s			
		Symptoms (SCL-90)	(D), (C), (S), D × C^s (−)			
Carayon (1992)	**He:** 122 office workers (70% ♀, 30% ♂) from a midwestern public service organization	1 (Indicators of worker strain: stable over time; after controlling for earlier health):		X	1 time lag of 1 year (**)	A: + B: −
		Boredom	(D), (C), (S)			
		Workload dissatisfaction	D^s, (C), S^s			
		Physical health complaints	D^s, (C), (S)			
Carayon (1993)	**He:** 122 office workers (70% ♀, 30% ♂) from a midwestern public service organization	1 (Indicators of worker strain: stable over time; after controlling for earlier health):		X	1 time lag of 1 year (**)	A: + B: −
		Daily life stress	(D), (C)			
		Physical health complaints	D^s, (C)			

(*table continues*)

Table 4 (*continued*)

Study	Population	Dependent variable(s)	Effects of DC/S dimension	Support strain hypothesis DC and/or DCS model	Time lag(s)	Evidence causation
Chapman et al. (1990)	**He:** 534 ♀, 2,100 ♂ Australian government employees working in Sydney (♂ from 8 diverse occupations, ♀ from 2 occupations)	3 Blood pressure	(D), (C), (S), $D \times C^s$ (−)	X	2 of 3 and 2 years (**)	A: − B: n.e.
Daniels and Guppy (1994)	**Ho:** 244 (86.1% ♂, 13.9% ♀) British accountants	1 Psychological well-being	D^s, (C), S^s, (D × C)	X	1 of 1 month (***)	A: + B: n.e.
de Jonge et al. (1998)	**Ho:** 261 (87% ♀, 13% ♂) nurses and caregivers	1 Burnout and job satisfaction		X	1 of 1 year (***)	A: + B: n.e.
		Emotional exhaustion	D^s, (C), S^s			
		Depersonalization	D^s, (C), S^s			
		Reduced personal efficacy	(D), (C), S^s			
		Job satisfaction	(D), C^s, S^s			
Dollard (1997)	**He:** 104 workers (51 ♂, 53 ♀); recruited from the general population (different occupations)	1		DC, DCS	1 time lag of 1 year (**)	A: + B: n.e.
		Physical health symptoms	(D), (C), (S), (D × C)			
		Work–home conflict	(D), (C), (S), (D × C)			
		Job satisfaction	(D), (C), S^s, $D \times C^s$			
Hjollund et al. (1998)	**He:** 430 (♀, ♂) couples (childless, wish for child; different occupations)	4 Fertility	(D), (C), (S) (#)	X	At least 5 of 28 days (****) for determining spontaneous abortion: 1 year after the measures	A: X B: n.e.
Johnson et al. (1995)	**Ho:** 495 (♀, ♂) graduates, working as physician	1		X	1 time lag of 1 year	A: + B: n.e.
		Psychiatric distress	(D), C^s, S^s			
		Job dissatisfaction	(D), C^s, S^s			
Landsbergis and Hatch (1996)	**He:** 717 ♀ workers (from Pennsylvania and New York; predominantly middle class; different occupations)	3 Pregnancy-induced hypertension	(D), (C), (#)	X	2 of 15 and 8 weeks (**)	A: X B: n.e.

Table 4 (*continued*)

Study	Population	Dependent variable(s)	Effects of DC/S dimension	Support strain hypothesis DC and/or DCS model	Time lag(s)	Evidence causation
Parkes (1982)	**Ho:** 164 student nurses (♂, ♀) British or Irish	1 Indicators of psychological distress	(D), (C), (S)	DC, DCS	4 of each approximately 6/7 weeks (**)	A: + B: n.e.
		Somatic symptoms	(D), C^s, S^s			
		Depression	(D), C^s, S^s			
		Anxiety	D^s, C^s, S^s			
		Social dysfunction	(D), C^s, S^s			
		Work satisfaction				
		2 Sickness absence	D^s, (C), (S)			
		Noncertificated sickness/absence (time)				
Parkes (1991)	**Ho:** 264 (93 ♂, 171 ♀) graduates taking a 1-year course leading to a teaching qualification	1991: 1 indicators of mental health		X	2 of 2 and 3/4 months (**)	A: + B: n.e.
		Anxiety	D^s, (C)			
		Social dysfunction	(D), (C)			
Parkes et al. (1994)	**Ho:** 264 (93 ♂, 171 ♀) graduates taking a 1-year course leading to a teaching qualification	1 indicators of somatic symptoms	D^s, (C), (S), D × C × S^s	DCS	1 of 2 months (**)	A: + B: n.e.
Steptoe et al. (1998)	**He:** 71 workers (44 ♀, 27 ♂) in the retail industry (mostly working in sales departments, some in distribution)	1 Indicators of well-being, job satisfaction, and work–home interference		DC, DCS	3:2 of 1 month and 1 of 2 months (**)	A: + B: n.e.
		Work and home interference	D^s, (C), (S)			
		Job satisfaction	D-C^s, S^s			
		Perceived stress	(D), (C), (S)			
		Psychological well-being	(D), (C), (S)			
		4 Cortisol	D-C^s (−), (S)			
		5 Smoking and alcohol consumption				
		Smoking behavior	(D), (C), (S)			
		Alcohol consumption	(D), (C), S^s			

(*table continues*)

Table 4 (*continued*)

Study	Population	Dependent variable(s)	Effects of DC/S dimension	Support strain hypothesis DC and/or DCS model	Time lag(s)	Evidence causation
Vahtera et al. (2000)	**He:** 530 municipal Finnish workers (138 ♂, 392 ♀, blue- and white-collar workers; different occupations)	2 Medically certified sickness absence rates	D^s, C^s (decision authority only), S^s, $D \times S^s$, $C \times S^s$	DC, DCS	2: 3 and 4 years (****)	A: + B: n.e.

Note. Detailed information about the ratings of the high-quality studies can be obtained from Annet H. de Lange. D = demands; C = control; S = social support; D^s = effect of job demands is significant; (D) = effect of job demands is *not* significant at $p < .05$; $D \times C^s$ = interaction effect between job demands and job control is significant; D-C = difference score used to indicate job strain; * = *insufficient;* ** = *sufficient;* *** = *good;* **** = *very good;* A = "normal" causation; B = "reversed" or "reciprocal" causation; n.e. = not explored; + = evidence for causal relationship; X = no evidence; (−) = results not in line with strain hypothesis of DC/S model or no causal effects found; (#) = some effects were found in subgroup analyses, not reported here. 1 = self-report measures for health and/or well-being; 2 = sickness absence measures; 3 = cardiovascular measures; 4 = other physiological measures; 5 = lifestyle factors; 6 = other measures (such as risk score based on different types of dependent outcomes; externally determined psychotic disorders).

somatic symptoms and job satisfaction across time, respectively. For the other outcomes in Dollard's (1997) study (physical health complaints and work–home conflict), no main or interaction effects were found. Further, Steptoe et al. (1998) found a significant effect of across-time difference scores for demands and control and a main effect of social support in predicting job satisfaction. No effects were found for perceived stress and psychological well-being. Thus, 6 of the 12 high-quality studies reported significant joint effects of the DC/S dimensions in predicting indicators of subjective well-being.

Apart from evidence for joint effects, 7 of the 12 studies (58%) presented evidence for (a) main effect(s) of the DC/S dimension(s) (i.e., no combined effects of DC/S dimensions in line with the strain hypothesis of DC/S model) and evidence for other effects of (combinations of) demands, control, and support in predicting self-report measures for health or well-being. In six instances (Carayon, 1992, 1993; Daniels & Guppy, 1994; de Jonge et al., 1998; Parkes, 1991; Steptoe et al., 1998), a main effect of demands was reported. Main effects of social support were reported by Carayon (1992), Daniels and Guppy (1994), de Jonge et al. (1998), and Johnson et al. (1995). Finally, de Jonge et al. (1998) and Johnson et al. (1995) reported main effects of control.

Sickness absence. Two high-quality studies (11%) measured sickness absence (Parkes, 1982; Vahtera et al., 2000). The study by Parkes (1982) revealed a main effect of demands in predicting (noncertified) sickness absence spells, whereas Vahtera et al. (2000) found interaction effects of demands and social support, and control and social support in predicting (medically certified) sickness absence rates.

Cardiovascular measures. Four studies (21%; Bosma et al., 1997; Bosma et al., 1998; Chapman, Mandryk, Frommer, Edye, & Ferguson, 1990; Landsbergis & Hatch, 1996) examined indicators of cardiovascular disease. None of these studies reported significant joint effects of job demands and control, at least not in the expected direction (see Chapman et al., 1990). Bosma et al. (1997, 1998) found significant effects of control in predicting indicators of cardiovascular disease, whereas Landsbergis and Hatch (1996) found no significant effects of the DC/S dimensions at all in their overall sample.

Other physiological measures. Two high-quality studies (11%; Hjollund et al., 1998; Steptoe et al., 1998) examined other physiological variables. Hjollund et al. (1998) reported no joint effects in predicting fertility, at least not for their total sample. Steptoe et al. (1998) found significant effects of across-time

difference scores for demands and control in predicting cortisol levels, but this effect was not in line with the strain hypothesis of the DC model.

Lifestyle factors. Two studies (11%; Bromet et al., 1988; Steptoe et al., 1998) measured lifestyle factors. Bromet et al. (1988) reported a multiplicative DC interaction effect in predicting alcohol-related problems. The study of Steptoe et al. (1998) revealed a significant main effect of social support in predicting alcohol consumption.

Other outcomes. Bromet et al.'s (1988) study measured externally determined episodes of depression, anxiety, and somatic symptoms. They found a significant DC interaction effect in predicting somatic symptoms, but this interaction was not in line with the DC model. For two other outcomes (depression and anxiety, as determined by experts in an interview), Bromet and his coworkers reported significant multiplicative interaction effects between demands and social support.

Support for the strain hypothesis of the DC/S model? Table 4 shows that three high-quality studies (Carayon, 1993; Landsbergis & Hatch, 1996; Parkes, 1991) explored the DC model, whereas the 16 other high-quality studies examined the DCS model. These 16 studies may provide support for the strain hypothesis of both the DC and the DCS model.

Table 4 shows that the three high-quality studies examining the DC model provided no support for the strain hypothesis. Two of the 16 high-quality studies examining the DCS model provided support for the DC model (Barnett & Brennan, 1997; Bromet et al., 1988), 1 study provided support for the DCS model (Parkes et al., 1994), and 5 studies (Bourbonnais et al., 1999; Dollard, 1997; Parkes, 1982; Steptoe et al., 1998; Vahtera et al., 2000) provided support for the strain hypothesis of both the DC and DCS model. Surprisingly, the study of Parkes et al. (1994) found only support for the strain hypothesis of the DCS model and not for the DC model. This result could be due to the fact that the authors did not control for the DC effects separately in their stepwise regression analyses (in the first steps, the influence of social support was also included).

More evidence in studies using heterogeneous populations? With the information presented in Table 4, we can also test the aforementioned assumption that heterogeneous populations are more useful for testing the effects of (combinations of) job characteristics. Of the high-quality studies, 11 studies (58%) are based on heterogeneous populations and 8 studies (42%) on homogeneous populations. Table 4 shows that 4 of the 11 heterogeneous studies (36%) provided evidence for the strain hypothesis (Barnett & Brennan, 1997; Bromet et al., 1988; Steptoe et al., 1998; Vahtera et al., 2000), whereas 4 of the 8 homogeneous studies (50%) also provided evidence for the strain hypothesis (Bourbonnais et al., 1999; Dollard, 1997; Parkes, 1982; Parkes et al., 1994). A Pearson chi-square test revealed that the number of studies supporting the strain hypothesis did not differ for homogeneous versus heterogeneous samples, $\chi^2(1, N = 19) = 0.35$, $p > .50$. Thus, studies using heterogeneous populations do not provide more evidence for the strain hypothesis than homogeneous populations.

In summary, only 8 of the 19 high-quality studies (42%) provided support for the strain hypothesis of the DC/S model; that is, they revealed joint effects of demands, control, or social support in predicting health outcomes over time (Barnett & Brennan, 1997; Bourbonnais et al., 1999; Bromet et al., 1988; Dollard, 1997; Parkes, 1982; Parkes et al., 1994; Steptoe et al., 1998; Vahtera et al., 2000). Consequently, the high-quality studies provide only modest support for the strain hypothesis of the DC/S model.

Causation

In spite of the modest support for the strain hypothesis, the studies do present clear evidence for causal relationships between work characteristics and health across time. Virtually all high-quality studies (with the exceptions of Chapman et al., 1990; Hjollund et al., 1998; Landsbergis & Hatch, 1996) provide evidence for a normal causal relationship between one or more of the dimensions of the DC/S model and the outcome variables. The studies of Carayon (1992, 1993) were the only high-quality studies that explicitly examined reversed or reciprocal causal relationships. These studies revealed only evidence for normal causal relationships.

When examining the DCS dimensions separately, the following findings emerge. Twelve high-quality studies (63%) reported significant main effects of *job demands* in predicting physical and psychological indicators of strain (mostly psychological well-being and sickness absence). The majority of these main effects occurred in conjunction with a main effect of control or social support. In addition, nine high-quality studies (47%) reported main effects of *job control* on the outcome variables (i.e., psychological distress, cardiovascular measures, and lifestyle factors). These main effects occurred usually in conjunction with a main effect of demands or social support. Furthermore, nine high-quality studies (47%) re-

ported main effects for *social support* in predicting psychological well-being and alcohol consumption. Again, the majority of these main effects occurred in conjunction with main effects of demands or control. Consequently, 16 studies (84%) provided evidence for normal causal effects of job demands, job control, or social support on various types of outcomes.

Discussion

The present article reviewed the methodological quality of 45 longitudinal studies examining the DC/S model using five evaluation criteria (study design, argument for the time lags used, quality of measures, method of analysis, and nonresponse analysis). Nineteen *high-quality* studies (42%) were identified, obtaining at least *sufficient* ratings on all criteria. Perhaps somewhat surprisingly, these studies provided only modest support for the strain hypothesis of the DC/S model. Only 8 studies (42% of the high-quality studies; Barnett & Brennan, 1997; Bourbonnais et al., 1999; Bromet et al., 1988; Dollard, 1997; Parkes, 1982; Parkes et al., 1994; Steptoe et al., 1998; Vahtera et al., 2000) demonstrated the expected *combination* of additive and multiplicative interaction effects of the DC/S dimensions, usually in the form of additive effects. Furthermore, our results indicate that studies based on heterogeneous populations (with more exposure contrast) do not provide more support for the strain hypothesis than studies based on homogeneous populations. This suggests that homogeneous populations provide enough true individual and within-occupation variation in job characteristics (i.e., provide enough exposure contrast) to be as useful as heterogeneous samples in testing the DC/S model.

Further, the fact that the included studies reported few interaction effects is consistent with previous (mainly cross-sectional) findings that multiplicative interaction effects are rare (Kasl, 1996; Kristensen, 1995; Theorell & Karasek, 1996). Most effects were found for the self-reported measures of health or well-being. Thus, the results of high-quality studies do *not* provide stronger support for the DC/S model than the mixture of excellent and not-so-excellent studies included in previous reviews. This implies that the results strongly resemble those obtained in reviews of cross-sectional studies, suggesting that the hints forwarded in previous research that the dimensions of the DC/S model affect worker health *causally* are not entirely based on wishful thinking combined with too-simple research designs. Moreover, 16 of the 19 high-quality studies (84%) included in this review provided clear support for normal causal relationships between work and health across time. Note, however, that the majority of these studies solely explored *normal* causal relationships; reversed or reciprocal causal relationships were only explored by Carayon (1992, 1993).

Study Limitations

Four limitations of this review are worth mentioning. First, the evaluation criteria that were applied in this review are not always applicable for every outcome variable. For example, this review evaluated a complete panel design as either *good* or *very good*, because this type of design provides the opportunity to examine all three types of causation. However, such a design is not always necessary, for example, when examining an outcome such as mortality. In this case exploring reversed or reciprocal causal relationships becomes superfluous, as the score on the outcome variable is irreversible once a particular end state has been reached. This problem follows directly from formulating general evaluation criteria for different kinds of outcomes. Moreover, the provided information on whether the selected studies tested different types of causation was not used for evaluating the studies.

A related limitation concerns the choice of evaluation criteria. Whereas the five criteria used in this study reflect common insights obtained from general and longitudinal research methodology, it is always possible to think of other criteria that might have been applied. One such criterion concerns the validity of the measures used, especially the measures for job demands and job control. It has been argued that global measures of job demands (e.g., the measures in Karasek et al.'s [1998] JCQ) may be ill-suited to measure the demands that are relevant in a particular occupation, meaning that using global measures will lead to underestimation of the effects of job demands on the outcome variables (de Jonge, Dollard, Dormann, Le Blanc, & Houtman, 2000). A similar case could be made for inclusion of job-specific control instead of using global control measures (cf. McLaney & Hurrell, 1988; Sargent & Terry, 1998). It would be interesting to see if studies using job-specific demands provide more support for the strain hypothesis compared with the results of studies using more global measures (e.g., the JCQ or similar instruments). Unfortunately, we were unable to examine this issue as only 5 of the 45 included studies (11%; Daniels & Guppy, 1994; Dollard, 1997; Johnson et al., 1995; Landsbergis & Hatch, 1996; Pollard

et al., 1996) used measures that might be construed as measures that were tailored toward the job or population under study.

Third, this review mainly paid attention to the results of the 19 high-quality studies; the other 26 studies were not examined in great detail. Our assumption was that evidence from methodologically impeccable longitudinal research on the DC/S model would be especially valuable in judging the evidence for the DC/S model. The results of the 26 other studies might present an under- or overestimation of the effects of work on health, as a result of different forms of bias. In other words, we can put less confidence in such results as we do not know how such low-quality research designs may have influenced the results reported in these studies. From this vantage point, inclusion of other, less well-designed studies is considered irrelevant. However, to examine whether the results of the high-quality studies differed from those obtained in the other studies, a limited comparison between the results of both types of studies was conducted. This analysis revealed that 11 of the 26 low-quality studies provided support for the strain hypothesis of the DC/S model (as defined in our introduction) compared with 8 of the 19 high-quality studies. A Pearson chi-square test revealed that the number of studies supporting the strain hypothesis did not differ as a function of study quality, $\chi^2(1, N = 45) = .60, p > .50$. Thus, the results from the 19 high-quality studies confirm the modest support found in earlier reviews (e.g., van der Doef & Maes, 1999).

A final limitation of this study is that some of the studies included in the present review were based on partly the same data set (Bosma et al., 1997, 1998; Carayon, 1992, 1993; Stansfeld et al., 1997, 1998, 1999; the first four studies were denoted as high-quality studies). This implies that the results of these studies are not statistically independent, meaning that they provide no statistically independent evidence regarding the effects of demands, control, and support. In both studies by Bosma et al. (1997, 1998), main effects of control were found, whereas the main effects of demands and support were not significant. In the Carayon (1992, 1993) studies no main effects of control were found, but job demands affected the outcome variables in both studies. As the results of these studies more or less counterbalance each other (control significant in one study but insignificant in another), our conclusions concerning the impact of demands, control, and support on the outcome variables do not change if these studies would not be taken into account.

Recommendations for Future Research

On the basis of this review, we highlight seven issues that would seem to deserve more attention in future research on the DC/S model.

1. *More research on specific (and "objective") outcomes*. The majority of the studies included in this review have examined self-report measures representing health or well-being and cardiovascular measures (see Schnall et al., 1994; Schnall, Belkić, Landsbergis, & Baker, 2000, for more comprehensive reviews on cardiovascular disease). High-quality longitudinal research examining other types of outcomes as sickness absence and physiological measures is clearly needed to provide a more complete picture of the effects of work characteristics on health and the mechanisms underlying these effects. In addition, the relative paucity of research using objective measures (such as registered sickness absence and mortality) makes it difficult to evaluate the value of the DC/S model in predicting these types of outcomes.

2. *More research on the effects of stable and changing DC/S dimensions over time*. Karasek and Theorell (1990) argued that the relation between duration of exposure to an unfavorable work situation and health may be nonlinear, such that long-term exposure has stronger detrimental effects than short-term exposure. Unfortunately, the majority of the high-quality longitudinal studies examined here have ignored the issue of *cumulative* exposure to high demands and low control (and low social support; "DC/S histories"). These studies mostly investigated the effects of Time 1 DC/S dimensions on Time 2 outcome(s). Consequently, the DC/S effects are based on a "one or two snap assessment" and not on longer DC/S histories. Similarly, only few longitudinal studies have addressed the health effects of *across-time change* in job demands and control. It would be particularly interesting to examine the effects of *change* in work characteristics on worker health: For example, does a change from a high-strain job to a low-strain job coincide with an improvement in worker health? Such research is scarce (for exceptions, see de Lange, Taris, Kompier, Houtman, & Bongers, 2002; Schnall et al., 1998; Swaen, Kant, van Amelsvoort, & Beurskens, 2002), yet this type of analysis would provide further validation of the DCS model.

3. *More research on the impact of different time lags*. Table 4 shows some consistent effects for, for example, the relationship between social support and job satisfaction (demonstrated with a time lag be-

tween 1 month or 1 year) and for additive effects of the DC/S dimensions on psychological well-being, burnout, and anxiety (demonstrated with a time lag of 1 year) over time. The results were less consistent for the other end points.

It is too early to draw strong conclusions from these results with respect to the "right" time lag for examining the effects of work characteristics on health, because the issue of which time lag is right depends on various factors, such as the type of outcome being measured, the amount of exposure to the stressors of interest, and whether changes in work characteristics or job changes have taken place. It is important that the time lag suits the process and etiology of the relationships between the research variables over time.

One recommendation that could be based on our findings is that researchers should design studies with many follow-up measures that are both evenly and unevenly spaced. By using unevenly spaced time lags, researchers can explore different effects of stressors over time; by using evenly spaced time lags, time-variant effects such as seasonal effects can be controlled for. On the other hand, researchers should realize that a design with many follow-up measurements might seriously reduce response among employees. Of course, in examining the impact of work characteristics on health, the effects of across-time change in job conditions must be considered (Landsbergis & Theorell, 2000; see Recommendation 2).

4. *More research using different cutoff points*. One standard approach to examining worker health in relation to the Karasek model is to examine worker health as a function of the type of job one holds: a high strain job, a low strain job, an active job, or a passive job. To obtain four job quadrants, one often dichotomizes demands and control using the median split. Sixteen of the 45 longitudinal studies used this "relative" approach. As yet, it is unclear whether the choice of the cutoff point influences results (Hammar, Alfredsson, & Johnson, 1998): Would results have been the same if a different cutoff point had been chosen? It is possible that in various studies the four Karasek job types are not that different at all. Given a particular amount of variation in job demands and job control, it is always possible to create the four Karasek job types; yet, due to restriction of range in some studies this variation might largely consist of error variance, meaning that no substantive health differences among the groups will be expected (no "objective" exposure contrast). In such cases, comparison of more extreme subgroups (i.e., groups that differ substantially as regards their amount of job demands and job control; e.g., based on 25th percentiles) may be a more fruitful approach. It is therefore important to explore in more detail effects of using various cutoff points.

Furthermore, any dichotomous method loses information when compared with using a continuous scale. Therefore, besides using information based on cutoff points, we advise the use of regression methods (retaining continuous scores) and the evaluation of the regression lines at fixed points above and below the mean from the regression equation (see Landsbergis & Theorell, 2000).

5. *More research on reversed and reciprocal causation*. Whereas it is widely acknowledged that work characteristics influence worker health, earlier research suggests that health may influence (the evaluation of) work as well (e.g., de Jonge et al., 2001; Taris, 1999). However, virtually none of the studies selected for this review examined the effects of health on work outcomes (with the notable exception of Carayon, 1992, 1993). Future longitudinal research on the DC/S model should address such questions to obtain a fuller understanding of the dynamic interplay between work and worker health, and to find out which path is dominant.

6. *More discussion concerning the impact of various confounders.* In Table 2 we described the different types of confounders that were controlled for in the 45 selected studies. Most of these ($N = 41$) controlled for demographic variables. Nevertheless, Table 2 also showed some inconsistency in the types of confounders controlled for in relation to the type of outcome. Some studies examining similar outcomes controlled for more confounders compared with others. We cannot draw any conclusions from our data as regards which (amount of) confounders should be controlled for when examining particular outcomes. Whether a researcher should control for a particular variable depends strongly on the process under study; but as the precise nature of this process is often largely unknown, deciding *which* variables should be controlled for is also unknown. However, future research should discuss in more detail why one should control for a particular confounder in relation to the nature of the process under study.

7. *More research examining the activation hypothesis*. The present review focused on the strain hypothesis of the DC/S model. However, Karasek and Theorell (1990) not only assumed that particular combinations of job characteristics lead to strain but also argued that some job types (i.e., active jobs) are conducive to learning, whereas other (passive) jobs inhibit learning (the *activation, motivation,* or *learn-*

ing hypothesis). As were earlier reviews (Kasl, 1996; Kristensen, 1995; van der Doef & Maes, 1999), the results of the present review are limited to the high-strain hypothesis of the DC/S model: Hardly any research explicitly addresses the activation (or motivation) hypothesis of the DC/S model (but see Holman & Wall, 2002; Taris, Kompier, de Lange, Schaufeli, & Schreurs, 2003, for a review). This would not be so important, were it not that Karasek and Theorell (1990) assumed that strain and learning mutually influence each other. For example, employees in active jobs will develop new skills that allow them to deal more effectively with the inevitably strain-inducing situations in their jobs. Thus, to obtain a fuller understanding of the relationship between work characteristics and health, more research on the activation hypothesis would seem desirable.

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Asterisks indicate the 45 studies included in this review.

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Received April 23, 2002
Revision received March 6, 2003
Accepted April 2, 2003 ■