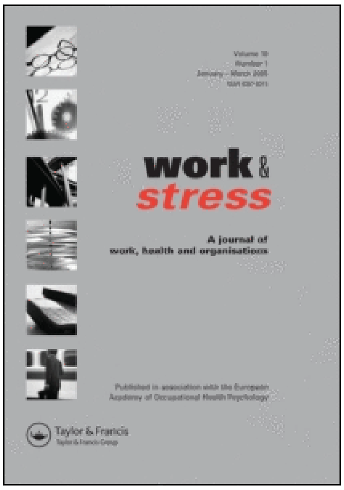

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Expanding the risk assessment methodology for work-related health: A technique for incorporating multivariate curvilinear effects

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Although there is conceptual and empirical evidence that supports the existence of possible curvilinear relationships between job characteristics and health outcomes, risk assessments usually rely on linear estimation approaches. However, this approach may not be conducive to good risk management practice. Where curvilinear effects exist, it is possible for there to be too much of a beneficial work characteristic, or too little of one that is harmful. If that is the case then there will be an optimum level for health and well-being. This study explores a new risk estimation technique that can accommodate multivariate curvilinear relationships. The partial derivatives technique can provide stronger predictive utility, incorporate synergistic effects of predictors, and is supported by conceptual work and empirical evidence. To illustrate these ideas, a risk assessment was conducted on a sample of 354 police officers in Greece. Multivariate polynomial regression analyses indicated that a number of job characteristics salient to participants' experiences were related to outcomes curvilinearly. A risk index (R_i) was derived from a range of values that represent the slopes of all possible lines tangential to the curve that describes the relationship between predictor and outcome. This technique may help to refine and extend current models of risk assessment for work-related health and stimulate new interest in research into risk assessment methodology.

Keywords: risk assessment; risk estimation; nonlinearity; curvilinear effects; work-related health; work-related stress; partial derivatives technique

Introduction

A risk management approach to dealing with work-related health is relatively well-established in the EU (Cox, Griffiths, Barlow, Randall, Thomson, & Rial-González, 2000; European Agency for Safety & Health at Work, 2007) and the USA (Quick, Murphy, & Hurrell, 1992; Sauter & Murphy, 1995), and is supported by guidance (Cousins, Mackay, Clarke, Kelly, Kelly, & McCaig, 2004; Cox, Karanika-Murray, Griffiths, Wong, & Hardy, 2009) and legislation (Framework Directive 89/391). Despite legal requirements and organizations' best intentions, the principles and practice of risk assessment for work-related health do not always concur. Although curvilinear relationships between job characteristics and work-related health have often been reported in the empirical literature, the tools commonly used for

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examining the impact of risks to health assume linear relationships (Karanika, 2006). Moreover, no guidelines exist on how to estimate risk in the presence of curvilinear effects. This can lead to inaccurate inferences about the impact of work on health and also wrongly inform risk management interventions. It is the aim of this paper to present (1) a case for extending the methodology of risk assessment to incorporate possible curvilinear effects of job characteristics on work-related health, and (2) an alternative way for estimating risk in a multivariate curvilinear context.

Current approaches

Risk assessment attempts to answer questions related to (1) the nature of the hazards faced by a specific population (risk identification), (2) the magnitude of the harm (harm estimation), (3) the extent of the risk posed, how significant it is and for whom (risk estimation) (Schrader-Frechette, 1998). Risk assessment outcomes are thus translated into a programme of risk reduction (Cox, 1993; Cox, Griffiths, & Randall, 2003). In line with the conditions for good science and in order to meet practical and ethical needs, risk assessment requires reliable and valid instruments and adequate data analysis (Cox & Griffiths, 1996).

Both the concept of risk assessment for work-related health and many of its quantitative tools have been adapted from the hard sciences (specifically engineering) and economics (Glendon, Clarke, & McKenna, 2006). Risk assessment has typically relied on probabilistic risk analysis, which places critical importance on the likelihood of a hazard occurring and the magnitude of its impact on a criterion variable (a work-related health outcome). For example, the European Agency for Safety and Health at Work (2007) uses an equation for calculating risk based on exposure/severity of consequences x probability (Clarke & Cooper, 2004). In this area, probabilistic risk analysis relies on odds ratios, correlations, and linear regression (Karanika, 2006). This approach is commonly applied to estimating the risk stemming from the work-related issues previously identified by the workers as salient to their work (e.g. Cox et al., 2000; Giga, Cooper, & Faragher, 2003; Jansen, Kompier, & Taris, 2005).

However, the techniques commonly used are univariate and based on an implicit assumption of linear relationships. By assuming univariate linear relationships, risk assessment may not always accommodate the complexity of work-related health (Karanika, 2006). In order to provide a fair evaluation of the work context, it is thus important that the effects of a variety of job characteristics on health are assessed simultaneously (Warr, 1994). Additionally, the assumption of linearity implies that certain job characteristics can only have negative effects on job-related outcomes, thus ignoring a multitude of potentially beneficial effects (e.g., Warr, 2007). Indeed, it has often been proposed that optimal levels of job characteristics lie away from their extreme scores (French, Caplan, & Harrison, 1982; McGrath, 1976). For example, both overload and underload have been reported as potential stressors (e.g., Friend, 1982; Kidd, 1961), placing optimal levels of workload somewhere in the middle of the continuum. In practice, identification of positive as well as negative aspects of work is invaluable for informing subsequent interventions (Griffiths, Cox, Karanika, Khan, & Tomás, 2006).

Ungrounded assumptions of linearity contradict existing conceptual and empirical work. Frese and Zapf (1988) recommended more attempts at curve-fitting for improving methodology in the area of work-related stress, while Zapf, Dormann, and Frese (1996) concluded that "linear data analysis methods would usually underestimate the true strength of the relationships" (p. 147). Social scientists have expressed discontent with the preoccupation with linearity (e.g., Abbott, 1988; Guion, 1998; Muse, Harris, & Feild, 2003; Schrader-Frechette, 1998). Ignoring possible curvilinear effects can produce inconsistent results when data are examined in linear terms (Ferris, Bowen, Treadway, Hochwarter, Hall, & Perrewé, 2006).

Extending current risk assessment models

To address these concerns, the risk assessment methodology should be extended to incorporate multivariate and possible curvilinear effects. Four good reasons support this.

Predictive utility. Risk assessment models that allow for curvilinear relationships could potentially explain a higher proportion of outcome variance than their linear equivalents. Many of the published studies that have explicitly compared linear and nonlinear approaches have concluded that models based on the latter have better model fit (e.g., Borg, Kristensen, & Burr, 2000; de Jonge, Reuvers, Houtman, & Kompier, 2000; de Jonge & Schaufeli, 1998; Karanika, 2006). The aim of a risk assessment is inevitably linked to its predictive ability, even when efforts to model the relationships between job characteristics and health outcomes are not explicitly led by theory. There is potential conceptual and empirical value in incorporating curvilinear effects in work-related health research in general (Karanika-Murray & Michaelides, 2008) and in risk assessment in particular.

Theoretical support. The case for curvilinear relationships between job characteristics and health outcomes is also supported by theory. For example, the assumption of nonlinearity between work and health is central in the Vitamin Model (Warr, 1987, 2007). Although vitamins (here representing job characteristics) generally improve human body functioning, continued intake can lead to either a constant effect, with no further improvement after a certain level (e.g., availability of money, valued social position), or to a decrement, where a vitamin becomes toxic after a certain level (e.g., opportunity for control, task variety). Rather than specifying a type of effect for each type of job characteristic, Warr groups them into 12 broad categories and 26 subcategories. Curvilinear relationships also indicate that job characteristics can act as both stressors and resources or motivators. The upward slope of the inverted-U curve is consistent with the positive linear theory of stress, which sees stress as motivating and a challenge, whereas the downward slope follows the negative linear theory, which holds that stress at any level is harmful and reduces performance (Jamal, 1985; Muse et al., 2003). Others have also alluded to but not elaborated upon possible curvilinear relationships between work and health (e.g., Cox, 1978; Karasek, 1979).

Empirical evidence. There is empirical evidence in the occupational health literature for the existence of nonlinear effects of work on affective and physical health. Available support has indicated curvilinear effects concerning skill discretion (Fletcher & Jones, 1993), social support (de Jonge & Schaufeli, 1998), job tension (Zivnuska, Kiewitz, Hochwarter, Perrewé, & Zellars, 2002), and decision latitude (Rydstedt, Ferrie, & Head, 2006) on job satisfaction. Job scope and complexity (Xie & Johns, 1995), job autonomy and social support (Borg et al., 2000) have also been linked to emotional exhaustion in a curvilinear way. Psychological demands and social support have been shown to have curvilinear effects on self-reported health (Borg et al., 2000). Finally, the effect on job tension of a supportive relationship with one's manager has been found to be curvilinear (Harris & Kacmar, 2006).

Empirical findings have not always been consistent, which makes the development of theory problematic. For example, in a sample of health care workers, Jeurissen and Nyklíček (2001) did not find any support for curvilinear effects of job demands and autonomy on job satisfaction, whereas de Jonge, Schaufeli, and Furda (1995) revealed unexpected inverted-U effects of social support on burnout. It should be acknowledged that perhaps the reason that few studies have reported curvilinear effects is not because the researchers ignore them, but because they do not exist. Nevertheless, we believe that there is enough empirical evidence to support the need for a risk estimation approach that accounts for curvilinear effects.

Synergistic and inhibitory effects. Psychosocial variables are multidimensional, interact in synergistic or inhibitory ways, and are time and context-dependent. Focusing only on bivariate relationships overestimate the importance of particular variables and may thus not be conducive to good risk management. Mediational relationships are not uncommon in psychosocial phenomena (Baron & Kenny, 1986; MacKinnon, Fairchild, & Fritz, 2007). It is therefore important to take a comprehensive approach to examining the impact of job characteristics on health outcomes, "rather than concentrating on one or two features in isolation" (Warr, 1994, p. 87). It is thus important to take a multivariate approach to risk estimation.

An alternative approach: risk estimation for curvilinear relationships

It seems that there are conceptual and empirical bases for examining curvilinear relationships between job characteristics and health outcomes, and for developing a multivariate curvilinear risk assessment. In this paper we describe and test a technique that represents an alternative to purely linear models and that can accommodate these needs. The partial derivatives technique for risk estimation is described here. (A paper that elaborates on the technique is also in preparation by the first and third authors.)

Odds ratios are used in risk estimation primarily because of their convenience and ease in both estimation and interpretation (e.g., Cox et al., 2000; Wang, Eddy, & Fitzhugh, 1995). An odds ratio indicates how much the likelihood of an outcome increases or decreases with a change in the independent variable (IV) for a particular group. In the case of many and continuous IVs, the odds ratio can be obtained through logistic regression. In the case of continuous IVs *and* a dependent variable (DV), odds ratios can only be estimated if the DV is transformed, often arbitrarily, into an ordinal. Alternatively, linear regression can be used. In this case, the β coefficient is the piece of information that is important for risk estimation: it indicates how much a DV changes given a change in the IV and is comparable to the information obtained from odds ratios. The mathematical rationale is as follows.

The derivative of the equation gives the *rate of change* of the DV, given an IV. In a *univariate linear model* this is simply the β coefficient which signifies the slope of the line. In a *univariate curvilinear model*, however, the derivative is not a single number but a line; for a curvilinear relationship signified by a quadratic equation

$y = \alpha + \beta_1 x + \beta_2 x^2 + e$, the differential equation $\frac{dy}{dx} = \beta_1 + 2\beta_2 x$ signifies the slopes of all the potential tangent lines on the curve (for every value of x). This equation can be used as an estimate of risk in curvilinear relationships in the place of the β coefficient as used in linear relationships. Therefore, when curvilinear relationships exist, risk is a range of possible values, each representing the possible lines tangential to the curve that describes the relationship between the IV with the DV.

Furthermore, in a *multivariate curvilinear model,* it is also possible to estimate the derivative of the regression equation, but this is done in respect to one IV only, with all other IVs treated as constants. This is the partial derivative. Thus, to find the risk for χ_1 for the regression equation $y = \alpha + \beta_1 x_1 + \beta_2 x_1^2 + \beta_3 x_2 + \beta_4 x_1 x_2 + e$, risk will be the partial derivative $\frac{\partial y}{\partial x} = \beta_1 + 2\beta_2 x_1 + \beta_4 x_2$. To estimate risk, values of χ_1 and χ_2 are substituted on the partial derivative.

In the present study, the partial derivatives approach was used to estimate risk in a multivariate curvilinear context. This technique aims to provide an avenue for expanding risk assessment methodology to take into account nonlinear relationships between job characteristics and outcomes. We believe that models which incorporate multivariate curvilinear effects of job characteristics will explain more variance in health-related outcomes than those that look at linear effects only. In the study described here, we tested this approach.

Method

Participants and procedure

A risk assessment for occupational health was carried out in the Hellenic Police force in Athens, Greece, after its management contacted the second author. The risk assessment framework is discussed elsewhere (e.g., Cox, 1993; Cox et al., 2003). Questionnaires were administered to the whole organization and 512 responses to the risk assessment survey were received (85% response rate of which 2.7% were females). The sample was split into managerial and operational rank male police officers because (1) initial discussions identified different work issues in the lower ranks of police officers than in the higher managerial ranks, (2) operational rank police officers are a homogeneous group (82% of the Hellenic Police force), and (3) females comprise a very small minority of this group and experience different types of stressor (Burke & Mikkelsen, 2005). The present analyses focus on operational rank male police officers ($N = 354$). Of the respondents, 75.3% were 36–45 years old and 89.3% were married. Mean tenure was 20.8 years ($SD = 5.5$). The Hellenic Police management group identified job-specific (job satisfaction) and context-free (physical health) outcomes as the criterion variables in the risk assessment.

Measures

The *job characteristics* experienced by operational rank male police officers were assessed for their degree of stressfulness by means of a survey, which was based on a preliminary study, as follows.

A list of job characteristics was developed on the basis of (1) the literature on police officers' work-related health and well-being (e.g., Collins & Gibbs, 2003; Maggiorou, 2005; Toch, 2000), (2) discussions with the Hellenic Police management group, and (3) participants' work experiences. A preliminary list of job characteristics was used to frame open-ended interviews with a representative sample ($n = 40$) who were asked to describe the problems and challenges that they experience in their daily work. Job characteristics were thus derived using a participatory ecological approach. Participatory approaches involve employees in the process (Cox et al., 2000), whereas ecological approaches consider the impact of environmental and organizational factors on individuals' experiences (Murphy, Bond, Beaton, Murphy, & Johnson, 2002). This provided a grounding of the survey items on the experiences of police officers (Toch, 2000) in a work environment that differs significantly from the rest of Europe (Smulders, Kompier, & Paoli, 1996).

All officers, including those interviewed in the preliminary study, were asked to complete, during or after work hours, a questionnaire. Respondents were asked to assess 62 aspects of their work (1 = does not cause stress at all, 6 = causes extreme stress). Principal components analysis with Varimax rotation was performed on these items in order to summarize them into broader categories (Ferguson & Cox, 1993). Sample size ($N = 354$) was good for the analyses on the basis of the 5:1 cases per item rule (Tabachnick & Fidell, 2001) (KMO = .85, > .60; Bartlett's $\chi^2 = 2640.66$, $df = 136$, $p < .01$). Variable inclusion proceeded iteratively with examination of communalities, loadings, item-total correlations, and total variance. The abridged 5-component solution incorporated 17 items and explained 69.69% of the variance. Components were interpreted as negative social image, limited (opportunities for) career development, unsupportive management, work–life imbalance, and workload. Cronbach's α were all $\geq .75$ indicating good reliability. Components were well-defined by the items with loadings $\geq .50$. Correlation coefficients between components ranged between .21 and .54, indicating that they were distinct from one another (Table 1). The detailed results of this analysis can be obtained from the first author.

Job satisfaction was assessed by the Job Satisfaction Scale, which covers intrinsic (7 items) and extrinsic (8 items) job satisfaction (1 = extremely dissatisfied, 7 = extremely satisfied; Cronbach's $\alpha = .90$ for the whole scale and .80 to .90 for the subscales, $N = 390$; Warr, Cook, & Wall, 1979). *Physical ill-health symptoms* were assessed using the relevant scale of the Occupational Stress Indicator (9 items; 1 = never, 7 = all the time; Cronbach's $\alpha = .78$, $N = 105$; Cooper, Sloan, & Williams, 1988). Scores were reversed prior to the analyses to simplify interpretation of the results. The survey was translated into Greek, back-translated by two researchers and cross-checked by a third.

Results

Second order polynomial regression analyses (Cohen & Cohen, 1983; Miles & Shevlin, 2001) were carried out to determine the impact of the five job characteristics on the three criterion variables. Evaluation of assumptions revealed some kurtosis and/or skewness, for which square root, logarithmic, and reciprocal transformations did not provide a substantial improvement. The original variables were retained. Prior to the analyses, the IVs were centred on zero to minimize collinearity between each and its quadratic term. The variance inflation factor (Fox, 2002), an indicator

Table 1. Partial correlations between predictors and outcomes (controlling for tenure).

	M	SD	Range of centred independent variables[a]	1	2	3	4	5	6	7	8	9
1. Negative social image	3.93	1.13	−2.93–2.07		.48**	.41**	.37**	.23**	−.28**	−.25**	−.23**	−.03
2. Limited career development	3.62	1.35	−2.61–2.39	.48**		.54**	.25**	.22**	−.26**	−.31**	−.30**	.01
3. Unsupportive management	4.60	1.03	−3.60–1.40	.41**	.54**		.36**	.21**	−.09	−.24**	−.28**	−.05
4. Work–life imbalance	4.89	1.19	−3.89–1.11	.38**	.25**	.37**		.28**	−.31**	−.35**	−.38**	.03
5. Workload	4.67	1.07	−3.67–1.33	.23**	.22**	.21**	.28**		−.21**	−.15**	−.20**	−.05
6. Physical health	4.95	1.09		−.28**	−.26**	−.09	−.31**	−.22**	(.87)	−.37**	−.38**	.09
7. Intrinsic job satisfaction	4.02	1.16		−.25**	−.32**	−.24**	−.36**	−.14**	.40**	(.82)	.81**	.17**
8. Extrinsic job satisfaction	3.89	1.08		−.23**	−.31**	−.28**	−.38**	−.20**	.39**	.81**	(.81)	.12*
9. Tenure	20.84	5.45										

*$p \leq .05$; **$p \leq .01$ (two-tailed).
Note: $N = 354$; Zero-order (Pearson) correlations are reported below the diagonal; Cronbach's α values for the outcome measures for this sample are reported on the diagonal; Perceived ill-health symptoms were reversed.
[a]This range was used for calculating the risk index (R_i) in Table 3. The range of responses for the job characteristics was 1-6.

of multicollinearity among predictors, was satisfactory for all models (2.55 to 1.02). The models were estimated with the software R 2.5.1 (Fox, 2002; R Development Core Team, 2008) using a hierarchical procedure in three blocks as shown in the tables. Tenure, age, and rank have been linked to employee health and job attitudes (e.g., Norris & Niebuhr, 1984) and were used as control variables in Block 1. The ratio of cases-to-IVs was generous. $N = 354$ fulfils the minimum of $50 + 8\ m$ (> 226) ($m =$ number of IVs; Tabachnick & Fidell, 2001). Power analysis indicated that to achieve a power of .95 with $p = .01$, $N = 354$ and 13 IVs, the effect size should be at least $f^2 = .08$, equivalent to $R^2 = .07$ (Cohen, 1988).

Table 2 displays R^2, ΔR^2, F, ΔF, B, and t values for the three models. Block 1 (control variables) had a significant impact on intrinsic job satisfaction ($R^2 = .03$) and extrinsic job satisfaction ($R^2 = .01$). Only tenure was significant and therefore rank and age were removed from the analyses. Block 2 models (linear terms) indicated significant impact for all three DVs ($R^2 = .18$ to .21) and were significantly different from Block 1 models ($\Delta R^2 = .17$, $\Delta R^2 = .18$, $\Delta R^2 = .20$). Block 3 models (quadratic terms) were also significant, reaching $R^2 = .26$ for physical health, $R^2 = .32$ for intrinsic job satisfaction, and $R^2 = .31$ for extrinsic job satisfaction.

Most importantly, the three curvilinear models were significantly different from the models with only the linear IVs, with additional variance explained reaching $\Delta R^2 = .08$ (physical health), .11 (intrinsic job satisfaction), and .10 (extrinsic job satisfaction). The models with the curvilinear IVs explained 1.44, 1.52, and 1.48 times or $\sim 50\%$ more variance than the models with only the linear IVs, supporting our proposition that incorporating multivariate curvilinear effects of job characteristics in our risk estimation models can explain more variance in outcomes than those that include linear effects only. The effects of some job characteristics in Block 2 became non-significant when the curvilinear terms were entered in Block 3 (Table 2). For example, the linear terms of limited career development and work–life imbalance had a significant impact on intrinsic job satisfaction. When curvilinearity was taken into account, negative social image and unsupportive management also emerged as significant. Thus, the linear-only models overlooked potentially important predictors of work-related health outcomes.

Risk estimation

As discussed, the estimate of risk in a multivariate curvilinear context (hereon referred to as the R_i index) is the derivative of the quadratic equation (see Introduction). As such, a range of R_i values can be specified, representing the varying slopes that the relationship between IV and DV can take at different values of the IV. It is also possible to estimate the tipping points of the curve where the slope is 0 by solving $\frac{dy}{dx} = \beta_1 + 2\beta_2 x$ for 0. Table 3 presents the values of R_i and the minima or maxima points for the three DVs. R_i values ranging from positive to negative denote an inverted U relationship, whereas those ranging from negative to positive denote a U relationship. In the case of work–life imbalance and intrinsic job satisfaction, both R_i values were negative, indicating that the relationship between these variables was negative with the negative slope becoming increasingly steeper ($-.16 \leq R_i \leq -.36$). As expected, risk was not uniform for all employees and at all

Table 2. Hierarchical regressions for physical health, intrinsic job satisfaction and extrinsic job satisfaction.

	Physical health						Intrinsic job satisfaction						Extrinsic job satisfaction					
	Block 1		Block 2		Block 3		Block 1		Block 2		Block 3		Block 1		Block 2		Block 3	
Independent variables	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*
Intercept	5.31	23.33***	5.28	25.16***	5.44	25.08***	3.23	13.39***	3.18	14.43***	3.63	16.29***	3.36	14.86***	3.34	16.29**	3.77	18.06***
Controls																		
Tenure	−.02	−1.72	−.02	−1.73	−.02	−1.84	.04	3.21**	.04	3.71***	.04	3.72***	.02	2.18*	.02	2.50*	.02	2.40*
Linear predictors																		
Negative social image			−.14	−2.41*	−.13	−2.27*			−.03	−.55	−.09	−1.53			.02	.28	−.01	−.24
Limited career development			−.16	−3.31**	−.16	−3.40***			−.19	3.73***	−.19	−3.89***			−.15	3.15**	−.15	−3.71**
Unsupportive management			.20	3.06**	.34	4.62***			.01	.16	.07	.91			−.06	−.99	.01	.21
Work–life imbalance			−.22	−4.31***	−.38	−5.63***			−.28	−5.35***	−.32	−4.71***			−.27	−5.53***	−.36	−5.59***
Workload			−.11	−2.15*	−.18	−3.17**			−.001	−.02	−.05	−.86			−.06	−1.16	−.13	−2.34*
Quadratic predictors																		
Negative social image					−.08	−2.02*					−.22	−5.55***					−.16	−4.30***
Limited career development					.01	2.28					−.08	−2.63**					−.07	−2.48*
Unsupportive management					.18	4.42***					.11	2.65**					.13	3.24**
Work–life imbalance					−.11	−3.27**					−.02	−.61					−.06	−1.73
Workload					−.10	−2.76**					−.06	−1.73					−.09	−2.78**
R^2		.01		.18		.26		.28		.21		.32		.01		.21		.31
F		2.97		12.65***		10.98***		10.29**		15.17***		14.67***		4.73*		15.35***		14.2***
$df1$, $df2$		1,352		6,347		11,342		1,352		6,347		11,342		1,352		6,347		11,342
ΔR^2				.17		.08				.18		.11				.20		.10

(*Table continues on next page*)

Table 2. (*Continued*)

	Physical health						Intrinsic job satisfaction						Extrinsic job satisfaction					
	Block 1		Block 2		Block 3		Block 1		Block 2		Block 3		Block 1		Block 2		Block 3	
Independent variables	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*
ΔF				14.47***		7.54***				15.72***		11.35***				17.26***		10.34***
$\Delta df1$, $\Delta df2$				5,347		5,342				5,347		5,342				5,347		5,342

*$p \leq .05$; **$p \leq .01$; ***$p \leq .001$.

Note: B = unstandardized regression coefficients; Block 1: Control variables (age, tenure, rank and gender; in order to use the categorical age and rank in the regression analyses each of the four categories was coded in separate dummy variables). Only the control variables with significant impact on the outcomes were retained. Block 2: Linear terms of the job characteristics. Block 3: Quadratic terms of the job characteristics.

Table 3. Risk estimation (R_i) for the three outcomes using the partial derivative.

	Physical health		Intrinsic job satisfaction		Extrinsic job satisfaction	
	R_i range	Minima/Maxima[a]	R_i range	Minima/Maxima	R_i range	Minima/Maxima
Negative social image	.34 to −.46	−.81	1.20 to −1.00	−.20	.93 to −.67	−.03
Limited career development	−.68 to .32	.80	.23 to −.57	−1.19	.22 to −.48	−1.07
Unsupportive management	−.96 to .84	−.94	−.72 to .38	−.32	−.93 to .37	−.04
Work–life imbalance	.48 to −.62	−1.73	−.16 to −.36	−8.00	.11 to −.49	−3.00
Workload	.55 to −.45	−.90	[b]		.53 to −.37	−.72

Note: The estimation of R_i (using the partial derivative) was based on the mean and range of the centred independent variables (see Table 1). Minima/maxima were calculated as the point where $R_i = 0$.

[a]See Table 1 for the range. [b]Neither linear nor quadratic models were significant, therefore R_i was not estimated.

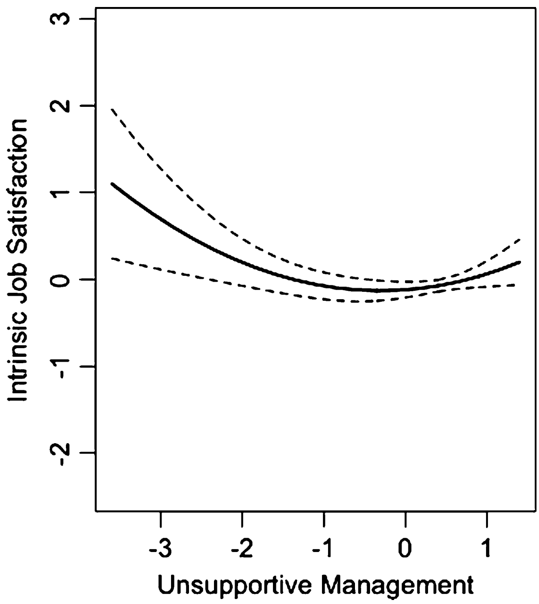

Figure 1. Relationships between unsupportive management (lower implies less stressful) and intrinsic job satisfaction (higher implies higher job satisfaction). The figure shows the plots for each term for the three models at Block 3 of the polynomial regression analyses. Dotted lines represent the pointwise standard errors.

values of the job characteristics. The interpretation of the R_i index is demonstrated below.

In the case of the impact of unsupportive management on intrinsic job satisfaction (see Figure 1), the risk estimate (R_i) was $.07+.11\ x$. The (centred) scale for unsupportive management (-2.39 to 2.07, see Table 1) was used to calculate R_i. Thus, $-.72 \leq R_i \leq .38$, with a minima of $-.32$. The relationship was of a U shape and there were two arms of the curve where intrinsic job satisfaction decreased as unsupportive management increased, up to a minima of $-.32$ after which intrinsic job satisfaction increased as unsupportive management also increased. R_i for physical health for those with the highest scores on unsupportive management (most stressful) was $-.72$, whereas the risk for those with the lowest scores on unsupportive management (least stressful) was .38, denoting that risk for those who scored high was .52 times higher than for those who scored low. In terms of unsupportive management and job satisfaction, R_i slopes were first negative and then positive: those who scored low on unsupportive management (least or not stressful) exhibited decreasing intrinsic ($R_i = -.72$) and extrinsic ($R_i = -.93$) job satisfaction, whereas those who scored high (most stressful) exhibited increasing job satisfaction ($R_i = .38$ and .37, respectively).

Similarly, in the case of the impact of increased workload on physical health (see Figure 2), the relationship was inverted-U: at low levels of increased workload the relationship was positive and physical health increased as workload increased. R_i for physical health for those who scored lowest on this IV was .55. This relationship was negative at the maxima of $-.90$ where additional levels of increased workload can

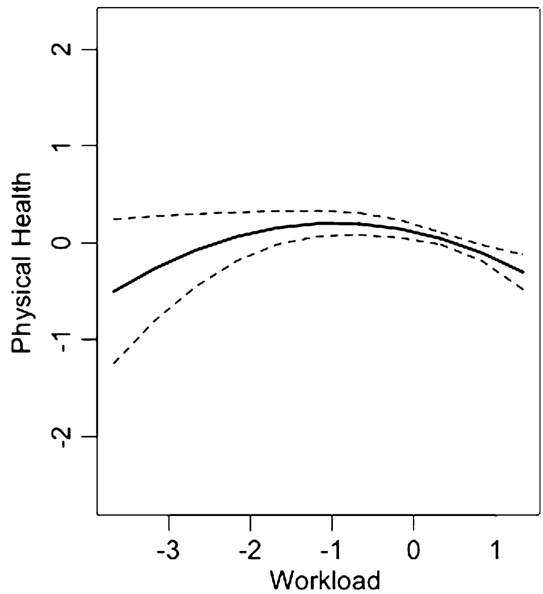

Figure 2. Relationships between workload (lower implies less stressful) and physical health (higher implies better health). Dotted lines represent the pointwise standard errors.

lead to reduced physical health. $R_i = -.45$ for physical health for those who scored highest on increased workload.

Finally, the relationships between extrinsic job satisfaction and negative social image, limited opportunities for career development, and increased workload were of an inverted-U shape (see Figure 3). At very low values, as these IVs increased so did extrinsic job satisfaction. As they became more stressful, extrinsic job satisfaction improved. Each of these had a maxima value or turning point, after which their impact became negative and increased stressfulness was linked to reduced extrinsic job satisfaction. The R_i values denote that the risk for those who scored 6 (most stressful) on these job characteristics was 4.63 to .70 times higher than for those who scored 1 (least or not stressful).

Discussion

The results of this study highlight the importance of an explicit focus in risk assessment methodology on the nature of the relationship between job characteristics and work-related health outcomes. The inclusion of both linear and curvilinear job characteristics in the study explained more variance in health outcomes than the linear only models. Most importantly, the partial derivatives technique for risk estimation illustrated in this study indicates that in the presence of curvilinear relationships risk is not a number (as with odds ratios and linear models) but a range of values that represent the possible lines tangential to the curve between predictor and outcome, and which can differ for different values of the predictor. A multivariate curvilinear approach can advance risk estimation for work-related health; it has predictive utility, is consistent with conceptual and empirical evidence, and

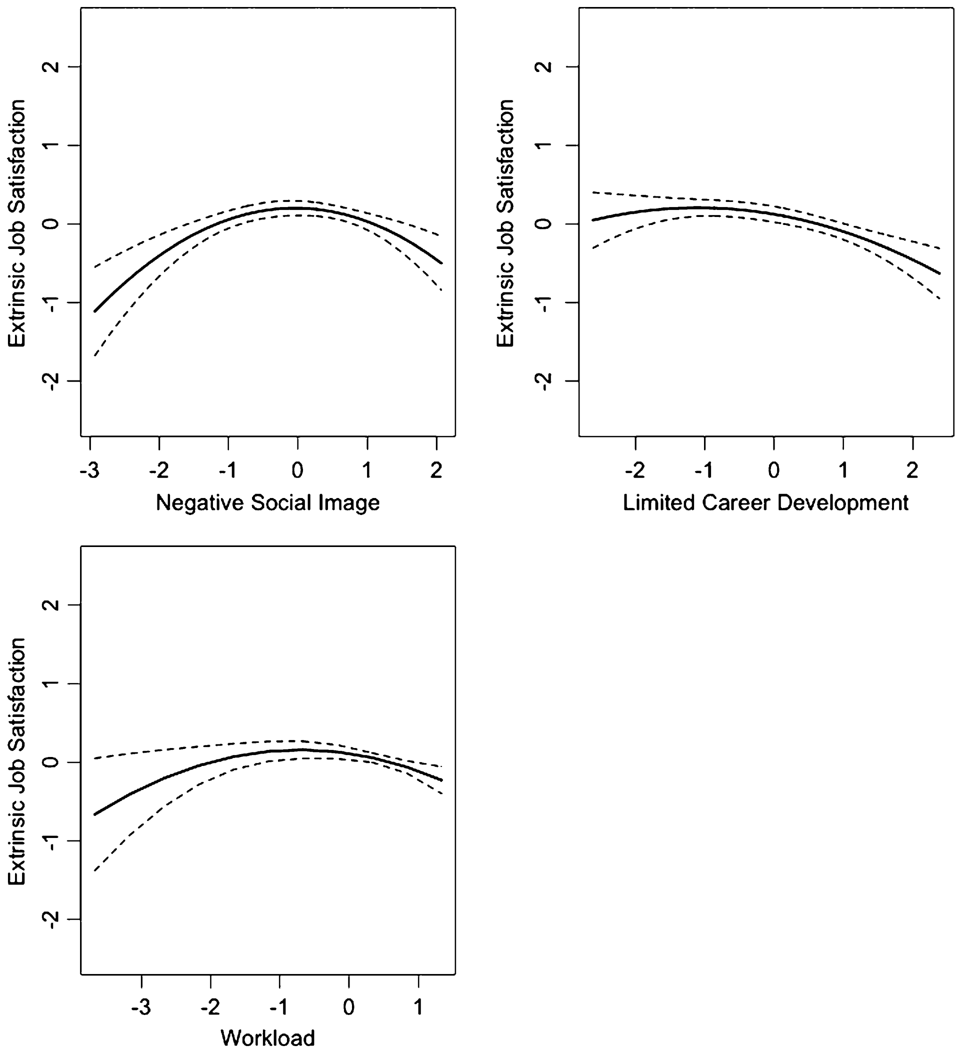

Figure 3. Relationships between negative social image, limited opportunities for career development, unsupportive management, and increased workload (lower implies less stressful) and extrinsic job satisfaction (higher implies higher job satisfaction). Dotted lines represent the pointwise standard errors.

incorporates possible synergistic or inhibitory effects of job characteristics on outcomes. The partial derivatives procedure that we have described can be easily translated into computational analysis tools for direct use by organizations and will hopefully also provide an impetus for further work into risk assessment methodology.

Implications for risk assessment

This proposed technique is feasible in practice and can also provide a new language for communicating risk to those responsible for managing work-related health in organizations. It is likely that incorporating curvilinear effects in risk estimation will provide more accurate models and make risk reduction actions more efficient and relevant to specific populations. A discussion of the implications for expanding risk assessment methodology follows next.

In risk assessment, the aim is not so much to explain as to predict (*predictive utility*). Introducing the *possibility* of curvilinearity in risk estimation can provide a more accurate picture of the effects of job characteristics on health outcomes. This is in line with empirical evidence that nonlinear analyses often provide better models of psychosocial phenomena than their linear equivalents (Borg et al., 2000; de Jonge et al., 2000; de Jonge & Schaufeli, 1998; Karanika, 2006). Failure to account for multivariate nonlinear effects can produce inconsistent results when data are examined in linear terms (the "paradox of disappearance"; Karasek, 1979). Consideration of linear and curvilinear effects in probabilistic risk assessment is a useful extension of current models. It can also help meet criticisms concerning the lack of adequate designs that enable the assessment of nonlinearity (Abbott, 1988; Ferris et al., 2006; Guion, 1998; Muse et al., 2003).

An approach that allows the consideration of multivariate impacts of job characteristics on work-related health can also potentially convey a more accurate view of effects than one that looks at variables in isolation (Warr, 1994) (*synergistic or inhibitory effects*). This necessitates a shift beyond the tendency to focus on one-cause-one-effect relationships to examining combinations of predictors (Adams & White, 2005; Kahn & Byosiere, 1992).

Third, the possibility that too much of an apparently beneficial job characteristic can be deleterious or that a little of a seemingly harmful one can be beneficial in a specific population or context has implications for designing risk management interventions. For example, in our sample the risk assessment highlighted the importance of a valued social position and the need for cultivating a positive image of the police (Reisig & Giacomazzi, 1998) especially in Greece (Maggiorou, 2005). Those who scored high on the perceived stressfulness of a negative social image had decreasing levels of physical health and job satisfaction, whereas those who scored low had increasing physical health and job satisfaction. Therefore, a programme aimed at reducing citizens' anxiety (e.g., Smith & Hawkins, 1973) but within some boundaries of respect for police officers' authority could be most beneficial. The examination of positive *and* negative work features is explicit in the economic approach to risk that "takes expected utility (benefit) rather than harm as the central criterion for managing risk" (Glendon et al., 2006, p. 19) and is also commonly used in risk management practice (e.g., Griffiths et al., 2006).

Finally, the multiple curvilinear effects technique for risk estimation opens up new possibilities for methodological developments. It underscores the need to expand probabilistic risk analysis beyond techniques borrowed from economics and engineering. The ideas presented here by no means represent the complete picture of how risk can be estimated in the context of multivariate curvilinear relationships. Further research will also be necessary to develop easy to use computational tools.

Interpretation of the findings

This study aimed to demonstrate a technique for risk estimation based on multiple curvilinear effects and to attempt to expand the methodology of risk assessment.

Although it was not our aim to explore current theory on the occupational stressors experienced by police officers, it may be necessary to discuss the findings in the light of their impact for extending risk assessment methodology as suggested here. All five job characteristics were associated with police officers' physical health and job satisfaction, thus corroborating previous work on similar samples (e.g., Brown, Fielding, & Grover, 1999; Kaufmann & Beehr, 1989). For example, poor management, structural reorganization, bureaucratic interference, and shiftwork have been linked to police officers' stress (Kop, Euwema, & Schaufeli, 1999), personnel policies and relationships with superiors have been related to anxiety (Storch & Panzarella, 1996), and most highly ranked occupational stressors seem to be work–life balance, lack of consultation and communication, lack of control over workload, and inadequate support (Collins & Gibbs, 2003).

Findings of curvilinear effects, however, can shed a somewhat different light by showing that less of an allegedly harmful aspects of work is not always better (less risk) and that mid-levels of some aspects can be optimal for health and well-being (zero risk). Concurring with an existing small body of work, the present study indicated that at low levels of negative social image, work–life imbalance, and workload, physical health tended to improve, whereas for those who scored high on these variables physical health tended to decrease. Risk can differ across individuals, depending on the way that an individual experiences a particular job characteristic. For all relationships examined there was a point (minima/maxima) where risk was zero (with the exception of the impact of work–life imbalance on intrinsic job satisfaction). Generally, at low levels of the job characteristics (rated as least stressful) the slope was positive and these outcomes improved as these job characteristics became slightly more stressful, but up to a certain level. At high levels of these job characteristics (most stressful), the slope was negative and as they become even more stressful, outcomes worsened.

This pattern was reversed for lack of opportunities for career development and unsupportive management. For those who scored very low on these job characteristics (least stressful) the slope was negative, indicating worsening physical health and declining job satisfaction. However, those for whom these job characteristics were highly stressful exhibited improving physical health and lower job satisfaction. Although these findings seem counterintuitive, the coping, social support, and motivation literatures can help to explain them. It is possible that after a certain point of low experienced managerial influence or support, individuals start to use or to rely more on personal or other resources. These, in turn, can increase their self-efficacy and perceived control. Perceived control can impact on motivation and coping (Wigfield & Eccles, 2000) and improve job satisfaction. Managerial support is linked to predictability and control at work, which has been associated with decreasing risk for heart problems (Väänänen et al., 2008). In addition, although managerial behaviours are an important determinant of job satisfaction (e.g., Arnold, Turner, Barling, Kelloway, & McKee, 2007), in a cross-cultural comparison Stordeur and colleagues (2002) found that "at the country-level, highest scores in leadership were not systematically followed by highest scores in job satisfaction" (p. 41), indicating that a number of additional individual and organizational factors may be important for explaining this relationship. In practical terms, risk management and health promotion could focus on preserving the positive side of the slope, where low levels of a particular job characteristic are associated with lower risk and a positive impact on outcomes (R_i is positive), or maintaining the maximum impact of the job characteristic at the tipping point of the curve before its impact becomes too much ($R_i = 0$). Therefore, our findings can add to the emerging literature on possible curvilinear effects that so far has presented a selective view of relationships between specific job characteristics and health outcomes (e.g., Borg et al., 2000; de Jonge et al., 2000; de Jonge & Schaufeli, 1998; Harris & Kacmar, 2006; Rydstedt et al., 2006; Xie & Johns, 1995; Zivnuska et al., 2002).

As mentioned, the impact of job characteristics on job satisfaction is not uniform for all individuals, but rather depends on how each individual perceives these job characteristics. This is in line with the curvilinearity hypothesis and the Vitamin Model (Warr, 1987, 2007). There is a point where the slope of the curve of the relationship between predictor and outcome changes direction ($R_i = 0$), showing that job characteristics can be construed equally as stressors and as resources. The upward slope of the inverted-U is consistent with the positive linear theory of stress, which sees stress as motivating and therefore a challenge, whereas the downward slope follows the negative linear theory, which holds that stress at any level is harmful and reduces performance (Jamal, 1985; Muse et al., 2003). Such a comprehensive approach allows for an open view to labelling job characteristics as either stressors or resources across different occupational groups and organizations. In practice, taking into account both potential positive and negative effects, or gains and losses, is a central concern in risk management (Glendon et al., 2006; Griffiths et al., 2006).

With regard to risk management, the complexity of organizational life poses unique challenges as well as opportunities (Cox, Karanika, Griffiths, & Houdmont, 2007). The limitations of this study relate to the use of self-report measures and its cross-sectional nature, and are exacerbated by inherent difficulties of conducting research in the police (due to issues related to culture, pride, or disclosure). For practical and ethical reasons, it is often impossible to conduct controlled research in organizations (Cox et al., 2007; Robson, 1993), rendering cross-sectional studies the most feasible approach. In addition, although self-report measures seem to provide an inaccurate reflection of the objective work environment (Jex, Beehr, & Roberts, 1992), there is some modest convergent validity of objective and self-report measures (Spector & Jex, 1991). Job strain is affected by both objective job characteristics and individuals' perceptions of these (Elsass & Veiga, 1997), thus rendering self-report measures as important perceptual measures in risk assessment.

Conclusions

By providing evidence to support the value of incorporating multivariate curvilinear effects in risk estimation methods, this study provided an alternative understanding of risk that we hope will contribute to a renewed interest in research into the methodology of risk assessment for work-related health. We have proposed and illustrated the partial derivatives technique for multivariate curvilinear risk estimation, and shown that in the presence of curvilinear relationships risk is not one value but a range of values depending on the individual's experience with a particular job characteristic. Incorporating curvilinearity in risk assessment can potentially provide more accurate models of the relationship between job characteristics and health outcomes, thus better informing risk management interventions.

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