

Chronobiology International

The Journal of Biological and Medical Rhythm Research

ISSN: 0742-0528 (Print) 1525-6073 (Online) Journal homepage: <https://www.tandfonline.com/loi/icbi20>

Toward a “Risk Index” to Assess Work Schedules

Simon Folkard & David A. Lombardi

To cite this article: Simon Folkard & David A. Lombardi (2004) Toward a “Risk Index” to Assess Work Schedules, *Chronobiology International*, 21:6, 1063-1072, DOI: [10.1081/CBI-200036919](https://doi.org/10.1081/CBI-200036919)

To link to this article: <https://doi.org/10.1081/CBI-200036919>



Published online: 07 Jul 2009.



Submit your article to this journal [↗](#)



Article views: 116



Citing articles: 29 View citing articles [↗](#)

Toward a “Risk Index” to Assess Work Schedules

Simon Folkard^{1,2,3,*} and David A. Lombardi²

¹Laboratoire d’Anthropologie Appliquée, Université René Descartes,
Paris, France

²Liberty Mutual Research Institute for Safety, Hopkinton, Massachusetts, USA

³Body Rhythms and Shiftwork Center, University of Wales Swansea,
Swansea, UK

ABSTRACT

This article describes our preliminary attempt to develop a Risk Index to estimate the risk of human error on different work schedules based on trends in the relative risk of accidents and injuries, rather than on hypothetical intervening variables such as alertness, fatigue, or performance on interpolated tasks. We briefly review trends in risk from the published epidemiological studies that have ensured that the a priori risk was constant. A simple Risk Index based on an additive model is developed on the basis of these trends, and we illustrate how it may be used to assess work schedules. Finally, we compare the results from this Risk Index with those from the UK HSE’s Fatigue Index and point out the discrepancies that emerge. We conclude that our risk-based modeling approach may assist in developing safer work schedules and also increase our understanding of this complex, multifaceted area.

Key Words: Work schedules; Worker safety; Occupational injuries; Work-place accidents; Mathematical models.

*Correspondence: Simon Folkard, Laboratoire d’Anthropologie Appliquée, Université René Descartes, 45 rue des Saints Pères, Paris 75006, France; Fax: +33-1-42-61-53-80; E-mail: s.folkard@swan.ac.uk.

INTRODUCTION

Safety is a primary concern in many work places, and this is particularly true in situations such as transport or the nuclear power industry where there may be a high public health or environmental risk (Ingre et al., 2004; Rajaratnam and Jones, 2004). A number of authors have produced models based on alertness, fatigue, or performance in an attempt to predict the likelihood of human error on different work schedules, and many of these were published in the Proceedings of the Fatigue and Performance Modelling Workshop (2002). These models have generated considerable interest since they offer a potentially simple mechanism for assessing the relative safety of different schedules. However, while some of them account for trends in the various measures of alertness and performance reasonably well, they cannot account for some relatively consistent trends in the relative risk of accidents and injuries, referred to collectively as incidents from hereon (Folkard and Tucker, 2003; Folkard and Åkerstedt, 2004). This is despite the fact that these trends were obtained in studies where the a priori risk appeared to be constant, or was corrected for, and hence the trends obtained could reasonably be assumed to reflect on variations in the likelihood of errors being made by the individual operators concerned.

In this article, we describe the initial findings from our development of a predictive model, based directly on the published trends in the relative risk of incidents, rather than using hypothetical variables such as alertness, fatigue, or performance on an interpolated task. In the vast majority of cases the incidents on which these trends are based were not severe; however, it is likely that they represent a relatively direct measure of the occurrence of human errors, i.e., mistakes and omissions. Many published studies of industrial accidents and injuries do not allow for an unbiased calculation of relative risk estimates due to nonhomogeneous a priori risk (for full details see Folkard and Tucker, 2003; Folkard and Lombardi, 2004). For example, the number of workers or the level of supervision may vary over the 24-hour day, as may the safety associated with the nature of the job tasks being performed. Thus longer, and hence safer, production runs are often kept for the night shift. However, a number of studies have attempted to correct for these confounders, such that any residual variation in risk could reasonably be assumed to reflect on the probability of the individuals concerned making an error. In our earlier research, we have demonstrated that there are four reasonably consistent trends in accidents and injuries associated with features of work schedules (Folkard and Tucker, 2003; Folkard and Åkerstedt, 2004).

Summary of the Trends

The first trend relates to the relative risk of incidents on the morning, afternoon, and night shifts of 8 h shift systems, i.e., shifts starting from about 05:00 to 08:00 h, 13:00 to 16:00 h, and 21:00 to 24:00 h, respectively. There are five studies that are based on relatively large numbers of incidents that appear to have overcome the potential confounders. In these studies, incident rates were reported separately for the morning, afternoon, and night shifts (for full details of the studies see Folkard and Åkerstedt, 2004). In addition, three studies reported two separate sets of data,



for different areas or types of incident, giving a total of eight data sets across the three shifts. While some of the studies give no precise details of the shift system in use, most of them involved a total of only 4 days on each shift before a span of rest days. Based on the pooled frequencies across these eight data sets, risk increased in an approximately linear fashion from morning to night, with an increased risk of 18% on the afternoon shift and of 30% on the night shift, relative to that on the morning shift (see for full details of this analysis Folkard and Lombardi, 2004). Thus, when the a priori risk appears to be homogeneous across the three shifts, there is a consistent tendency for the relative risk of incidents to be significantly higher on the afternoon than morning shift, and for it to be highest on the night shift.

The second trend relates to relative risk of incidents over successive night shifts. The authors are aware of a total of seven published studies that have reported incident frequencies separately for each night over a span of at least four successive night shifts (for details of these studies see Folkard and Åkerstedt, 2004). Based on the pooled frequencies across these seven data sets, incident risk was about 6% higher on the second night, 17% higher on the third night, and 36% higher on the fourth night, relative to that on the first night shift. Two important questions arise over this substantial increase in risk over the four successive night shifts. First, what is the risk of an incident over longer spans of successive night shifts? However, this cannot currently be addressed since there is a paucity of data relating to it (see Folkard and Lombardi, 2004). Thus, it is possible that over longer spans of night shifts risk may actually start to decrease again.

The second important question is whether the increase in risk over successive shifts is confined to the night shift, or whether it occurs across all shifts, possibly representing an accumulation of fatigue over successive workdays. Of the seven studies that provide data on the trend over successive night shifts, five also reported the risk over successive morning or day shifts.^a Based on the pooled frequencies across these five data sets, the risk of an incident was about 2% higher on the second day, 7% higher on the third day, and 17% higher on the fourth day shift than on the first shift. These results suggest clear evidence of an increased risk over successive day shifts, but that this increase is substantially smaller than that over successive night shifts.

The fourth trend considers the impact of different lengths of shift on risk. Studies that have interpolated performance measures have typically found a deterioration in performance and alertness on 12 h compared to 8 h shifts (e.g., Rosa, 1991). Four studies have recently reported a trend in the risk of incidents over successive hours on shift and have managed to correct for exposure (i.e., a priori risk) in some manner. These studies were reviewed in detail by Nachreiner (2000) and Folkard and Lombardi (2004). For this trend, it was not possible to sum the frequencies since each of the trends had to correct for exposure in some way, and thus combining raw frequency scores would be biased. Rather, the mean risk for the

^aThe term “day shift” is usually used in 12 h shift systems for the shift that starts in the morning. For the sake of simplicity it is used from hereon to refer to both day and morning shifts.



first 8 h was set at one, and then hourly relative risk values were calculated for each study. These relative risk values were then averaged to produce a combined trend.

Apart from a slightly heightened risk from the second to fifth hour (see Folkard, 1997; Tucker et al., 2000 for a discussion of this), risk increased in an approximately exponential fashion with time on shift such that it was more than doubled in the twelfth hour relative to the average for the first 8 h. Using this combined trend, relative risk was estimated for shifts of different lengths by averaging the hourly risk values involved in each length of shift. Note that this set the risk of an 8 h shift to one due to the procedure described above. This resulted, relative to 8 h shifts, in an estimated 13% increase in relative risk for 10 h shifts and 27% increase in relative risk for 12 h shifts.

Finally, it is important to note that the trend for hours on duty does not control for the influence of breaks during a duty period. A number of laboratory studies have been conducted on the effects of breaks (e.g., Dababneh et al., 2001), but there appears to be only a single study that has examined the impact of rest breaks on incident risk (Tucker et al., 2003). This study examined industrial injuries in an engineering plant in which breaks (of 15, 45, and 10 min, respectively) were given after each 2 h period of continuous work. The number of injuries within each of the four 30 min periods between breaks was calculated, and the risk in each 30 min period was expressed relative to that in the first 30 min period immediately following the break. The results indicated that risk rose substantially, and approximately linearly, between successive breaks, such that risk had doubled by the last 30 min period before the next break. It is also noteworthy that there was no evidence that this trend differed between the day and night shifts, or for the three successive 2 h periods of continuous work within each shift.

Combining the Relative Risk Estimates

Given that the trends previously described are based upon estimates of the relative risk of incidents, the combined effects of the type of shift, the number of successive shifts, shift length, and the interval between breaks can be estimated in a relatively straightforward manner. This is illustrated using a model in which the individual effects are assumed to combine in a simple additive manner. However, the use of a multiplicative model would likely result in an essentially similar pattern of results for normal ranges of shifts. The additive model or "Risk Index" can be expressed simply as:

$$[formula 1] RR_S = RR_T + CR_N + CR_L + CR_B$$

where

RR_S = Relative risk for a span of shifts,

RR_T = Relative risk for the first shift of this type in the span,

CR_N = Change in risk for the number of successive shifts of that type in the span,

CR_L = Change in risk for the length of the shifts in the span, and

CR_B = Change in risk for the interval between breaks.



The relative risk of the first shift in a span of a given type (RR_T) must be estimated before this model can be applied. This value differs from the values given above for the morning, afternoon, and night shifts; those values were based on spans of four shifts, and it is known that the trend over successive shifts differs depending on the type of shift. However, since both the (i) risk over a span of four shifts is 30% higher on the night than day shift and (ii) size of the increase in risk over successive day and night shifts are known, it is possible to calculate the relative risk on the first shift of a given type in any span of shifts. If we set the risk on the first day shift to 1.00, then we can calculate the relative risk on the first night shift as being 1.19. Likewise, by taking account of the increase over successive shifts of a given type, we can calculate the estimated risk on each successive shift, whether it be a day or night shift.

Rather than express the relative risk of different shifts, spans of shifts, and durations of shifts relative to a single 8 h day shift, it would seem appropriate to use the reference of a “standard” working week. Thus, the relative risk on a span of five successive 8 h day shifts was set to 1.00, and the relative risks for all other combinations were expressed relative to this. We also set the “standard” interval between breaks at 4 h, i.e., a single mid-shift break on an 8 h shift, or two equally spaced breaks on a 12 h shift. Finally, least-squares linear fits to the trends (i) over successive shifts and (ii) between breaks were used to estimate the relative risk associated with different lengths of spans of shifts and intervals between breaks. Where necessary, these linear fits were extrapolated to estimate the risks associated with longer spans of shifts or longer intervals between breaks.

Deriving Predictions from the Risk Index

The Risk Index (Formula 1) was then used to estimate the relative risk for different combinations of shift length and span of successive shifts. This was done separately for spans of day shifts and for spans of night shifts. The estimated relative risk increased with both the number of shifts in the span and with the length of those shifts. Further, the estimated relative risk associated with night shifts was always higher for any given span or shift duration than that for day shifts, as would be expected from the trends discussed previously, while the buildup in the estimated relative risk associated with increasing span length was greater for night than for day shifts.

The Risk Index (Formula 1) was also used to estimate the length of the span of different shift durations that would result in an approximately equal relative risk. This is important when designing new or alternative shift systems since it enables the estimation of whether a new shift system is likely to be more or less risky than the current one. For example, if a company is currently operating a system involving six successive 8 h night shifts and wants to use longer night shifts, it might be interested in determining the length of the span of 10- or 12 h nights that would result in the same relative risk as the six successive 8 h shifts in its current system. The Risk Index estimates that the relative risk on a span of six successive 8 h night shifts is 1.44 and that this is approximately the same as that for a span of four 10 h or two 12 h night shifts.



The Risk Index (Formula 1) can also be used to estimate the trend in the relative risk over a span of different shifts, such as those entailed in the 8 h 2-2-3 or “Continental” shift system that is used throughout Europe. Typically, in this type of shift rotation, no shift is worked for more than three days and rests days are factored into the shift cycle. In order to estimate the risk on this type of system, we need to make an additional assumption as to what happens to the relative risk at the change from one type of shift to another. The most parsimonious assumption would appear to be that the “increment” in relative risk at this point is the sum of (i) the increment that would have occurred had the type of shift not changed and (ii) the difference in RR_T between the two types of shift involved in the change.

Based on this assumption, it is then possible to use the Risk Index to estimate the relative risk for each shift in the span of seven successive shifts. For the purpose of illustration, we have taken a span comprising two morning shifts, followed by two afternoon shifts, and then by three night shifts. The estimated relative risk values for each shift in the span are shown in Figure 1 as shaded bars. This figure also shows the change in the estimated relative risk between adjacent pairs of shifts (line graph). Two things are apparent from this figure. First, it is clear that the estimated relative risk increases substantially over the successive shifts in the span. Secondly, the magnitude of the increase in estimated relative risk between any pair of successive shifts varied depending on their type. Thus, the increase was greater at the change from one type of shift to another, and greater between successive night shifts than between successive morning or afternoon shifts. Finally, by averaging the relative risk estimates for the seven individual shifts it was also possible to estimate that the

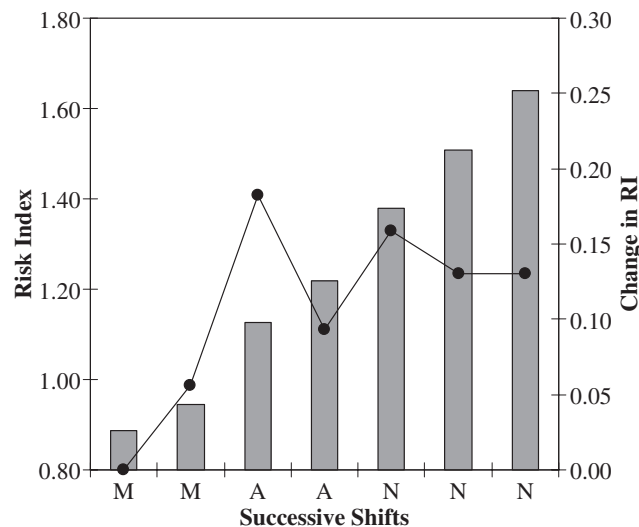


Figure 1. The Risk Index values over the successive shifts in a span of shifts (shaded bars, left-hand scale) and the change in magnitude of these values from one shift to the next (line graph, right-hand scale). M, A, and N on the x-axis stand for morning, afternoon, and night shifts.



overall relative risk for the entire span of shifts was 1.24, i.e., 24% higher than that for a span of five successive 8 h day shifts.

Comparison with HSE Fatigue Index

In the UK the Health and Safety Executive (HSE) has produced a “Fatigue Index” to assess the likely fatigue, or assumed risk, on different work schedules (see Rogers et al., 1999). This index has been widely promoted in the UK and is used by consultants and various organizations. We compared the output from the Risk Index with that from the Fatigue Index. The first comparison we made was for spans of four successive day shifts, varying in length from 8 to 12 h in 1 h intervals, with all starting at 07:00 h.

The squared correlation coefficient (R^2) for the best fitting linear regression between the two sets of 20-day shift values produced in this manner was 0.72 ($p < 0.001$) (see Figure 2). However, despite this statistically significant cross-correlation, there were clear discrepancies in risk estimation between the two approaches. First, the fatigue index failed to show any increase over successive day shifts unless they were at least 11 h long, despite clear evidence for such an effect in the relative risk data described previously in this article. Second, with respect to the cumulative effect over spans of 11- or 12 h day shifts, the Fatigue Index showed

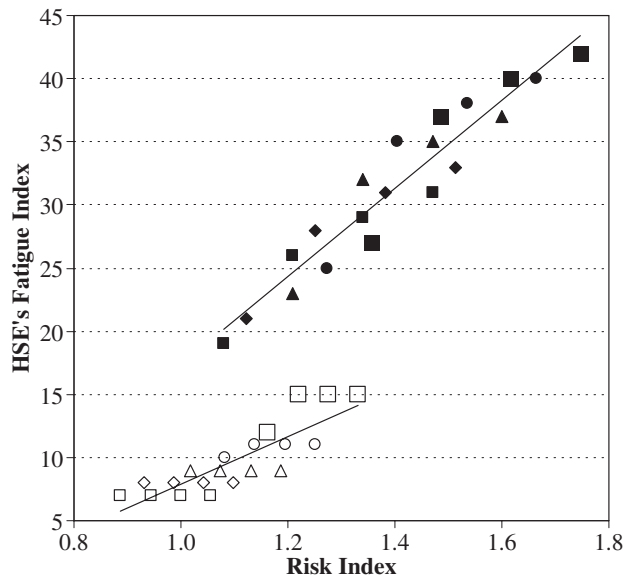


Figure 2. Comparison of the outputs of the HSE Fatigue Index and Risk Index for spans of four day (open symbols) and night (filled symbols) shifts. The lengths of the shifts in the spans were 8 h (■), 9 h (◆), 10 h (▲), 11 h (●), and 12 h (■). Note that the first, second, third, and fourth shifts within each span always read from left to right in this figure. Also shown are the best fitting linear regressions, fitted separately to the day and night shifts (—).



an increase from the first to the second shift, but no increase over subsequent day shifts; whereas, the relative risk data (see previous section) and the Risk Index suggest a fairly linear increase over successive shifts.

The second comparison was made for spans of four successive night shifts, again varying in length from 8 to 12 h, and all starting at 19:00 h. The R^2 for the best-fitting linear regression between the two sets of 20 night-shift values was 0.91 ($p < 0.001$) (see Figure 2). Again, however, there was a clear discrepancy in that the Fatigue Index showed a fairly large increase from the first to the second night shift within the spans of different-length shifts, and a much smaller increase between subsequent shifts within each span. In contrast, the relative risk data (see previous and Folkard and Lombardi, 2004) and the Risk Index suggest a fairly linear increase over spans of successive night shifts.

Finally, all the day- and night-shift values were combined together into a single analysis. The R^2 for the best-fitting linear regression between the two datasets of 40 values was 0.83 ($p < 0.001$). Again, despite this highly significant fit, a final clear discrepancy emerges from inspection of Figure 2. Namely the Fatigue Index substantially underestimated the risk on day shifts relative to that on night shifts (or overestimated the risk on night relative to day shifts) in comparison to the risk data from the epidemiological studies (see previous) and Risk Index. This weakness in the Fatigue Index is essentially recognized by the HSE in their notes on its use, since they suggest a higher value as an “acceptable limit” for night (35) than for day shifts (30).

CONCLUSIONS

Three main conclusions can be drawn from the results in this article. First, there are some relatively consistent trends in the risk of incidents, and hence presumably in the risk of human error, associated with specific features of shift systems. However, these trends are not always quite what may be predicted from considerations of psychological factors, such as fatigue, alertness, and performance (see Folkard and Åkerstedt, 2004, for a more detailed discussion). Accidents and injuries are likely multicausal, and there may be many other important worker-related (e.g., psychological) factors that underlie accident risk. In addition, it is possible that the relationship between the risk of human error and factors such as fatigue, alertness, and performance may be nonlinear (see Folkard and Åkerstedt, 2004, for a more detailed discussion). In other cases it is possible that at least some of the variation in risk represented residual, i.e., noncontrolled or corrected for, work-equipment factors (e.g., equipment malfunction) and/or work-environment factors such as work pressures (see Oginski et al., 2000).

Second, it would seem both feasible, and potentially very useful, to base a Risk Index on the trends in risk associated with specific features of shift systems. Like any type of statistical model the predicted values derived from it can only be as precise as the data on which it is based, and the current version of the Risk Index is clearly limited in a number of ways. For example, while it can be used to derive risk estimates for a wide variety of shift systems, including backward rotating ones, it cannot take account of the “quick returns” often associated with backward rotating shift schedules. There is, however, at least one study of the impact of quick returns



on injury frequencies (Macdonald et al., 1997); so, it may prove possible to take account of these in a future version. Likewise, the current version of the Risk Index is limited to shifts starting at “standard” times of the day, and thus, it cannot be used for very early morning starts or for irregular work schedules. Nor can it currently take account of the number of successive rest days between spans of shifts. Clearly there is a strong need for further well-designed epidemiological studies in this important area to allow these factors to be addressed in future versions of the Risk Index.

Despite these obvious shortcomings, the current version of the Risk Index would appear to have at least two distinct advantages over the alternative models that have been based on fatigue, alertness, or interpolated performance measures (Fatigue and Performance Modeling Workshop, 2002). Thus, the relative risk estimates derived from the Risk Index can be easily understood, have a high face validity, and should, at least in time, prove easy to verify or dispute. In addition, the Risk Index addresses the safety problems associated with shift work directly and does not rely on hypothetical intervening variables.

Finally, the output from the Risk Index compares favorably with that from the UK HSE’s Fatigue Index, but suggests various ways in which the latter could be improved. In summary, it would seem that a risk-based modeling approach may not only help develop safer work schedules, but also increase our understanding of this complex, multifaceted area.

ACKNOWLEDGMENTS

We are grateful to Dr. Gordon S. Smith and two anonymous referees for their thoughtful comments on an earlier draft of this manuscript. This paper was written while the first author was the 2004 Visiting Scholar at the Liberty Mutual Research Institute for Safety.

REFERENCES

- Dababneh, A. J., Swanson, N., Shell, R. L. (2001). Impact of added rest breaks on the productivity and well-being of workers. *Ergonomics* 44:164–174.
- Fatigue and Performance Modelling Workshop. (2002). Proceedings published in *Aviation, Space and Environmental Medicine* 75(suppl. 1):A1–A199(1).
- Folkard, S. (1997). Black times: temporal determinants of transport safety. *Accident Analyses and Prevention* 29:417–430.
- Folkard, S., Åkerstedt, T. (2004). Trends in the risk of accidents and injuries and their implications for models of fatigue and performance. *Aviation, Space and Environmental Medicine* 75 (suppl. 1):A161–A167(1).
- Folkard, S., Lombardi, D. A. (2004). Designing safer shift systems. In: Nickel, P., Grzech-Sukalo, H., Haenecke, K., Schutte, M., eds. *Arbeits- und Organisationspsychologie—Impulse aus Oldenburg*. Frankfurt am Main: Peter Lang, *in press*.



- Folkard, S., Tucker, P. (2003). Shiftwork, safety and productivity. *Occupational Medicine* 53:95–101.
- Ingre, M., Kecklund, G., Åkerstedt, T., Kecklund, L. (2004). Variation in sleepiness during early morning shifts: a mixed model approach to an experimental field study of train drivers. *Chronobiol. Int.* 21(6):973–990.
- Macdonald, I., Smith, L., Lowe, S. L., Folkard, S. (1997). Effects on accidents of time into shift and of short breaks between shifts. *International Journal of Occupational and Environmental Health* 3:S40–S45.
- Nachreiner, F. (2000). Extended work hours and accident risk. In: Marek, T., Oginska, H., Pokorski, J., Costa, G., Folkard, S., eds. *Shiftwork 2000—Implications for Science, Practice and Business*. Kraków: Institute of Management, Jagiellonian University, pp. 29–44.
- Oginski, A., Oginska, H., Pokorski, J., Kmita, W., Gozdzia, R. (2000). Internal and external factors influencing time-related injury risk in continuous shift work. *Int. J. Occup. Safety and Ergonomics* 6:405–421.
- Rajaratnam, S. M. W., Jones, C. B. (2004). Lessons about sleepiness and driving from the Selby rail disaster: *R v Gary Neil Hart*. *Chronobiol. Int.* 21(6):1073–1077.
- Rogers, A. S., Spencer, M. B., Stone, B. M. (1999). *Validation and Development of a Method for Assessing the Risks Deriving from Mental Fatigue*, HSE Contract Research Report 254/1999; HMSO: Norwich.
- Rosa, R. (1991). Performance, alertness and sleep after 3.5 years of 12 h shifts: a follow-up study. *Work and Stress* 5:107–116.
- Tucker, P., Folkard, S., Macdonald, I. (2003). Rest breaks reduce accident risk. *Lancet* 361:680.
- Tucker, P., Sytnik, N., Macdonald, I., Folkard, S. (2000). Temporal determinants of accident risk: the “2–4 hour shift phenomenon.” In: Hornberger, S., Knauth, P., Costa, G., Folkard, S., eds. *Shiftwork in the 21st Century*. New York: Peter Lang, pp. 99–105.



Request Permission or Order Reprints Instantly!

Interested in copying and sharing this article? In most cases, U.S. Copyright Law requires that you get permission from the article's rightsholder before using copyrighted content.

All information and materials found in this article, including but not limited to text, trademarks, patents, logos, graphics and images (the "Materials"), are the copyrighted works and other forms of intellectual property of Marcel Dekker, Inc., or its licensors. All rights not expressly granted are reserved.

Get permission to lawfully reproduce and distribute the Materials or order reprints quickly and painlessly. Simply click on the "Request Permission/Order Reprints" link below and follow the instructions. Visit the [U.S. Copyright Office](#) for information on Fair Use limitations of U.S. copyright law. Please refer to The Association of American Publishers' (AAP) website for guidelines on [Fair Use in the Classroom](#).

The Materials are for your personal use only and cannot be reformatted, reposted, resold or distributed by electronic means or otherwise without permission from Marcel Dekker, Inc. Marcel Dekker, Inc. grants you the limited right to display the Materials only on your personal computer or personal wireless device, and to copy and download single copies of such Materials provided that any copyright, trademark or other notice appearing on such Materials is also retained by, displayed, copied or downloaded as part of the Materials and is not removed or obscured, and provided you do not edit, modify, alter or enhance the Materials. Please refer to our [Website User Agreement](#) for more details.

[Request Permission/Order Reprints](#)

Reprints of this article can also be ordered at

<http://www.dekker.com/servlet/product/DOI/101081CBI200036919>