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Analyzing Seasonal Variations in Suicide With Fourier Poisson Time-Series Regression: A Registry-Based Study From Norway, 1969–2007

Jørgen G. Bramness*, Fredrik A. Walby, Gunnar Morken, and Jo Røislien

* Correspondence to Dr. Jørgen G. Bramness, Norwegian Centre for Addiction Research, Institute of Clinical Medicine, University of Oslo, Kirkeveien 166, 0407 Oslo, Norway (e-mail: j.g.bramness@medisin.uio.no).

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Seasonal variation in the number of suicides has long been acknowledged. It has been suggested that this seasonality has declined in recent years, but studies have generally used statistical methods incapable of confirming this. We examined all suicides occurring in Norway during 1969–2007 (more than 20,000 suicides in total) to establish whether seasonality decreased over time. Fitting of additive Fourier Poisson time-series regression models allowed for formal testing of a possible linear decrease in seasonality, or a reduction at a specific point in time, while adjusting for a possible smooth nonlinear long-term change without having to categorize time into discrete yearly units. The models were compared using Akaike's Information Criterion and analysis of variance. A model with a seasonal pattern was significantly superior to a model without one. There was a reduction in seasonality during the period. Both the model assuming a linear decrease in seasonality and the model assuming a change at a specific point in time were both superior to a model assuming constant seasonality, thus confirming by formal statistical testing that the magnitude of the seasonality in suicides has diminished. The additive Fourier Poisson time-series regression model would also be useful for studying other temporal phenomena with seasonal components.

seasonal variation; suicide

Abbreviations: AIC, Akaike's Information Criterion; ANOVA, analysis of variance.

Relatively stable seasonal variations in suicide rates were first observed by Durkheim in the 19th century (1), with a peak in the spring, most often cited as April–June. The phenomenon has subsequently been observed in many countries (2). Researchers have reported that seasonality is most pronounced in so-called "violent suicides," that is, suicide by hanging, firearms, knives, etc. (3–5). However, such studies have been criticized for having an indiscrete division between violent and nonviolent methods (6). Studies which divide suicides into more specific categories by suicide method have produced mixed results, with seasonality being both present (4) and absent (7) in methods that could be grouped together as "violent." Seasonality is seen most prominently in male suicides (8, 9), but it is unclear whether this association is related to suicide method, since men are more likely to use methods described as violent. As long ago as Durkheim's time, it was observed that the seasonal association was most pronounced in rural areas (1), a finding which has subsequently been both replicated (2, 10) and refuted (11).

Correlations between seasonality in suicides and seasonality in various psychiatric disorders have been described in ecological studies (12). More pronounced seasonality in suicide rates has been linked to comorbid conditions such as alcohol dependence (13), psychiatric disorders themselves (14–16) or their treatment (17), and allergies and asthma (18, 19). Interestingly, there also seems to be seasonal variation in neuroendocrine functions (20), serotonin levels (4), melatonin levels (21), cholesterol levels (22), and immunological parameters (23)—all with possible links to depression and suicide.

It has been proposed that the seasonality in suicides is declining. While long time series (24) and studies comparing 2 time periods far apart (25) have indicated some decrease in seasonality, other studies have shown no decrease (26), and some have even shown an increase (27). It is only possible to confirm a small reduction in seasonality with long time

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series. In a review by Hakko et al. (5) of 46 studies, the median study length was only 9 years, and only 1 study had an observation period of more than 30 years. Ultimately, the suggested decline in seasonality of suicides is yet to be confirmed.

Statistical methods for a proper analysis of possible change in seasonality in suicide counts are limited, and methodological mistakes are common (6). Using too rough a model, such as simple χ^2 tests in the analysis of monthly data, is a common source of flawed results (6). Edwards' test (28, 29) performs distinctly better in detecting seasonal patterns in aggregated data than the χ^2 test (6), but Edwards' test is restricted to unimodal sinusoidal patterns, and observations show that seasonality contains more complex patterns.

In order to account for the temporal aspects of monthly counts, traditional time-series analysis seems like a plausible alternative. Decomposition of time series will separate trends, cycles, and random fluctuations (6), while autoregressive integrated moving average models disentangle the time series into autoregressive and moving average components, together with detrending. A seasonal component may also be included. Unfortunately, traditional time-series analysis tends to focus on forecasting capabilities, and conclusions regarding seasonality can only be drawn in an indirect manner (6). Neither of the methods above allow for formal statistical testing of a temporal change or, more specifically, a decrease in the seasonality of suicides. Similar issues hold for wavelets, another methodological approach frequently used for time-series data (30). Wavelets allow for modeling of seasonality and examination of trends in the intensity of seasonality over time, and while wavelet methods intended for formal statistical testing of nonstationary behavior exist (31, 32), the framework is mathematically complex and results are difficult for the general medical researcher to interpret.

An alternative to traditional time-series analysis when analyzing monthly counts is Poisson time-series regression. In a comparison of the use of time-series analysis and Poisson regression for detecting a shift in rates of child injury after an intervention in New York, Kuhn et al. (33) deemed Poisson regression to be an attractive alternative to time-series analysis. Time-series Poisson regression analysis has been used to analyze the association between dengue fever and weather in China (34). Analyzing seasonality using Poisson regression by including a few select sine and cosine functions has been suggested (35), and this approach has been applied for analyzing seasonality in road injuries (36).

Poisson time-series regression is promising, but incomplete. Rather than postulating a few select trigonometric functions for modeling seasonality in suicides, we suggest fitting a full Fourier series—that is, including the full range of possible trigonometric functions—and selecting the optimal subset of these by means of some objective model selection criteria. Additionally, rather than categorizing time into yearly units, we suggest modeling the underlying long-term temporal change in the data using splines. Modeling and testing a possible change in seasonality over time can then be done formally by adding interaction terms between time and various model terms in the proposed additive Fourier Poisson time-series regression model and testing for the statistical significance of these interaction terms.

Our aim in this study was to explore a possible decrease in seasonality over the years by formal temporal statistical testing, primarily in the data set as a whole and secondarily in subgroups of suicides, such as those based on biological sex and method of suicide. Various additive Fourier Poisson time-series regression models were fitted to data on all suicides occurring in Norway during the 39-year period 1969–2007.

METHODS

Data set

Suicide data were obtained from the Cause of Death Register maintained by Statistics Norway. Data on all suicides taking place in Norway during the 39-year period from January 1969 to the end of December 2007 (20,156 deaths in total) were included in the analyses. Data were aggregated to monthly counts in order to explore both long-term trends and seasonal patterns (468 months in total).

Among the 20,156 suicides, 5,391 (26.7%) occurred among women and 14,765 (73.3%) occurred among men. Causes of suicide were classified as violent or nonviolent. Hanging, shooting, fires, and using a car, knife, or gun were classified as violent suicides ($n = 13{,}099$; 65.0%). Nonviolent suicides included drowning and poisoning ($n = 7{,}057$; 35.0%). The most frequent causes of suicide were hanging/strangulation ($n = 6{,}149$; 30.5%), poisoning ($n = 5{,}235$; 26.0%), shooting ($n = 4{,}842$; 24.0%), drowning ($n = 1{,}776$; 8.8%), jumping from a high place (934; 4.6%), the use of a sword or dagger (505; 2.5%), and jumping or lying in front of other moving objects (504; 2.5%).

Statistical analysis

In this study, we analyze suicide counts rather than suicide rates. Focusing on the latter would involve scaling monthly suicide counts with the yearly inhabitant information available from Statistics Norway, consequently introducing a step function into an otherwise time-continuous process, effectively changing time from a continuous predictor to a categorical predictor. Categorization of continuous predictors in multiple regression models has been thoroughly examined in the statistical literature and repeatedly argued against (37–39). The issue of different resolutions can be handled using standard interpolation techniques, but the lack of detailed information remains. According to data from Statistics Norway, the Norwegian population increased relatively linearly throughout the 39-year study period (40). Thus, analyzing suicide counts is here an undistorted, conservative approach, while analyzing suicide mortality rates would introduce a bias of unknown direction and magnitude.

Seasonality can be understood as the component of a time series representing the repetitive and predictable fluctuations around the trend line in 1 year. To explore whether the seasonality of monthly suicide counts has decreased over the years, we fitted additive Fourier Poisson time-series regression models. Poisson regression is part of the generalized linear model framework, also including linear and logistic regression for continuous and dichotomous outcomes, respectively. Poisson regression has the natural logarithm as the link

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function, and our regression model for the monthly suicide count n_t was thus built as

$$\ln[E(n_t)] = c + l_t + s_t,$$

with c a constant, l_t the long-term temporal trend, and s_t the seasonality component. Modeling of the various terms is described below.

Statistical model

Allowing for nonlinearity in the long-term temporal trend in monthly suicide counts l_t, we turned to generalized additive models (41). Generalized additive models is a natural extension of the generalized linear model framework to allow for nonlinearity. Rather than fitting linear terms of time t, one fits a smooth function $f(t)$, often by fitting a spline, that is, a set of higher-order polynomials. Thus, an additive Poisson time-series regression model encompassing the long-term temporal trend only is

$$\ln[E(n_t)] = c + f(t). \tag{1}$$

The optimal spline can be found using the generalized cross-validation criterion (41).

The seasonal pattern s_t is an additional nonlinearity in the data, one that repeats every 12 months. The Fourier series expansion theorem states that any repeating signal with time period T can be fitted using a summation of sine and cosine functions of various frequencies and amplitudes. For monthly data, $T = 12$. We used Fourier series to fit the seasonality component, that is, linear combinations of sine and cosine functions (35). The optimal combination of sines and cosines in the suicide counts is unknown but can be estimated from the data. Assuming the same seasonality component across the full 39-year study period results in the model

$$\ln[E(n_t)] = c + f(t) + \sum_{k=1}^{12}\left[a_k \cos\left(\frac{2\pi kt}{T}\right) + b_k \sin\left(\frac{2\pi kt}{T}\right)\right], \tag{2}$$

allowing for simultaneous estimation of both a nonlinear long-term temporal trend and a repeating seasonal pattern.

To explore whether the seasonal pattern in monthly suicide counts decreased in magnitude over the course of the observation period, we fitted 2 alternative models. First we explored whether there was evidence of a linear decrease in the monthly number of suicides, adding the interaction term

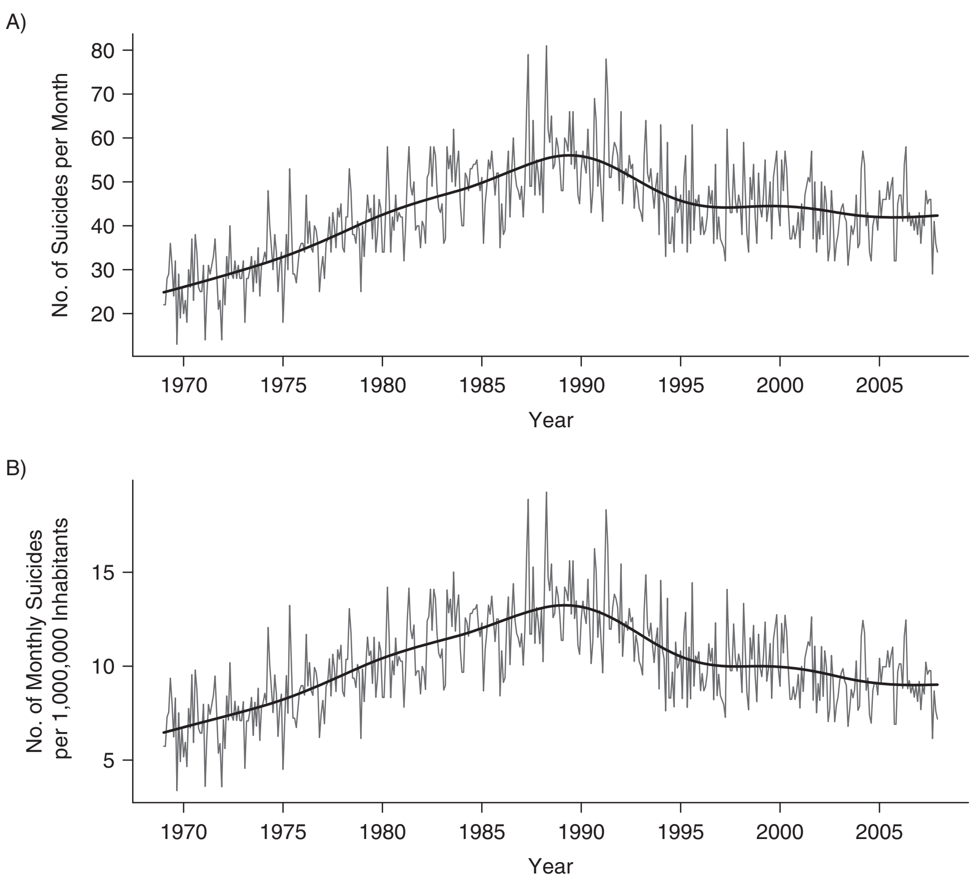

Figure 1. Monthly suicide counts (A) and monthly suicide rates (B) in Norway, 1969–2007. The figure shows the raw data (peaks and valleys) with the estimated long-term trend from a generalized additive model superimposed (curve).

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"time × seasonal pattern" to the regression model (equation 2):

$$\ln[E(n_t)] = c + f(t) + \sum_{k=1}^{12}\left[a_k \cos\left(\frac{2\pi kt}{T}\right) + b_k \sin\left(\frac{2\pi kt}{T}\right)\right] + t \times \sum_{k=1}^{12}\left[\alpha_k \cos\left(\frac{2\pi kt}{T}\right) + \beta_k \sin\left(\frac{2\pi kt}{T}\right)\right]. \quad (3a)$$

As an alternative, we fitted a change-point model assuming that the seasonal component was constant up to a change point t_γ, after which the seasonal component changed to a different constant level,

$$\ln[E(n_t)] = c + f(t) + \sum_{k=1}^{12}\left[a_k \cos\left(\frac{2\pi kt}{T}\right) + b_k \sin\left(\frac{2\pi kt}{T}\right)\right] + I(t \geq t_\gamma) \times \sum_{k=1}^{12}\left[\widetilde{\alpha}_k \cos\left(\frac{2\pi kt}{T}\right) + \widetilde{\beta}_k \sin\left(\frac{2\pi kt}{T}\right)\right]. \quad (3b)$$

Table 1. Comparison of the Use of Different Additive Fourier Poisson Time-Series Regression Models in the Analysis of Temporal Suicide Data, Norway, 1969–2007

Data Set and Model	Akaike's Information Criterion	*P* Value[a]
All Suicides		
Model 1[b]	3,151.5	
Model 2[c]	3,066.3	<0.001
Model 3a[d]	3,055.0	<0.001
Model 3b[e]	3,050.5	<0.001
Men		
Violent suicides[f]		
Model 1	2,815.5	
Model 2	2,761.7	<0.001
Model 3a	2,761.4	0.117
Model 3b	2,753.3	0.002
Nonviolent suicides[g]		
Model 1	2,345.6	
Model 2	2,332.2	<0.001
Model 3a	2,331.5	0.094
Model 3b	2,325.6	0.005
Women		
Violent suicides		
Model 1	1,972.8	
Model 2	1,966.7	0.006
Model 3a	1,964.0	0.016
Model 3b	1,955.2	<0.001
Nonviolent suicides		
Model 1	2,195.7	
Model 2	2,195.7	<0.001
Model 3a	2,161.8	0.019
Model 3b	2,156.2	0.002

[a] Model 2 was tested for significance against model 1, whereas models 3a and 3b were both tested against model 2.
[b] Model without seasonality (equation 1).
[c] Model with constant seasonality throughout the observational study period (equation 2).
[d] Model with a steady decrease in seasonality (equation 3a).
[e] Model with a change point (equation 3b).
[f] Hanging, shooting, fires, and using a car, knife, or gun were classified as violent causes of suicide.
[g] Nonviolent causes of suicide included drowning and poisoning.

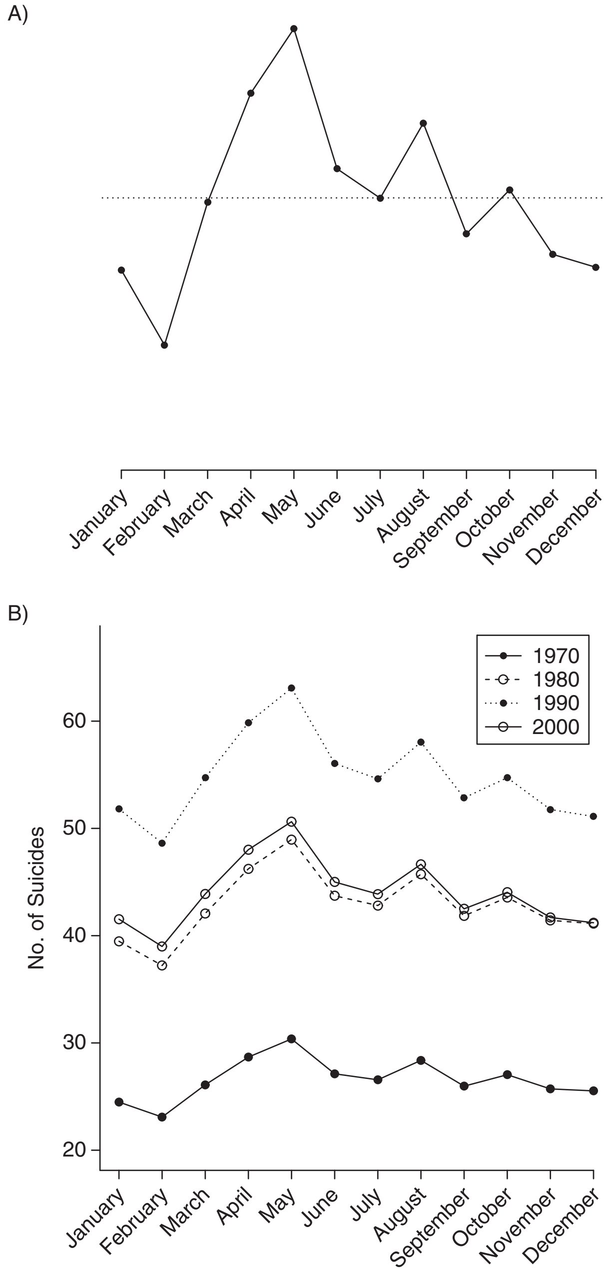

Figure 2. Normalized seasonal pattern of suicide in Norway across the whole 39-year observation period (1969–2007) (A) and exemplified for 4 specific years (B).

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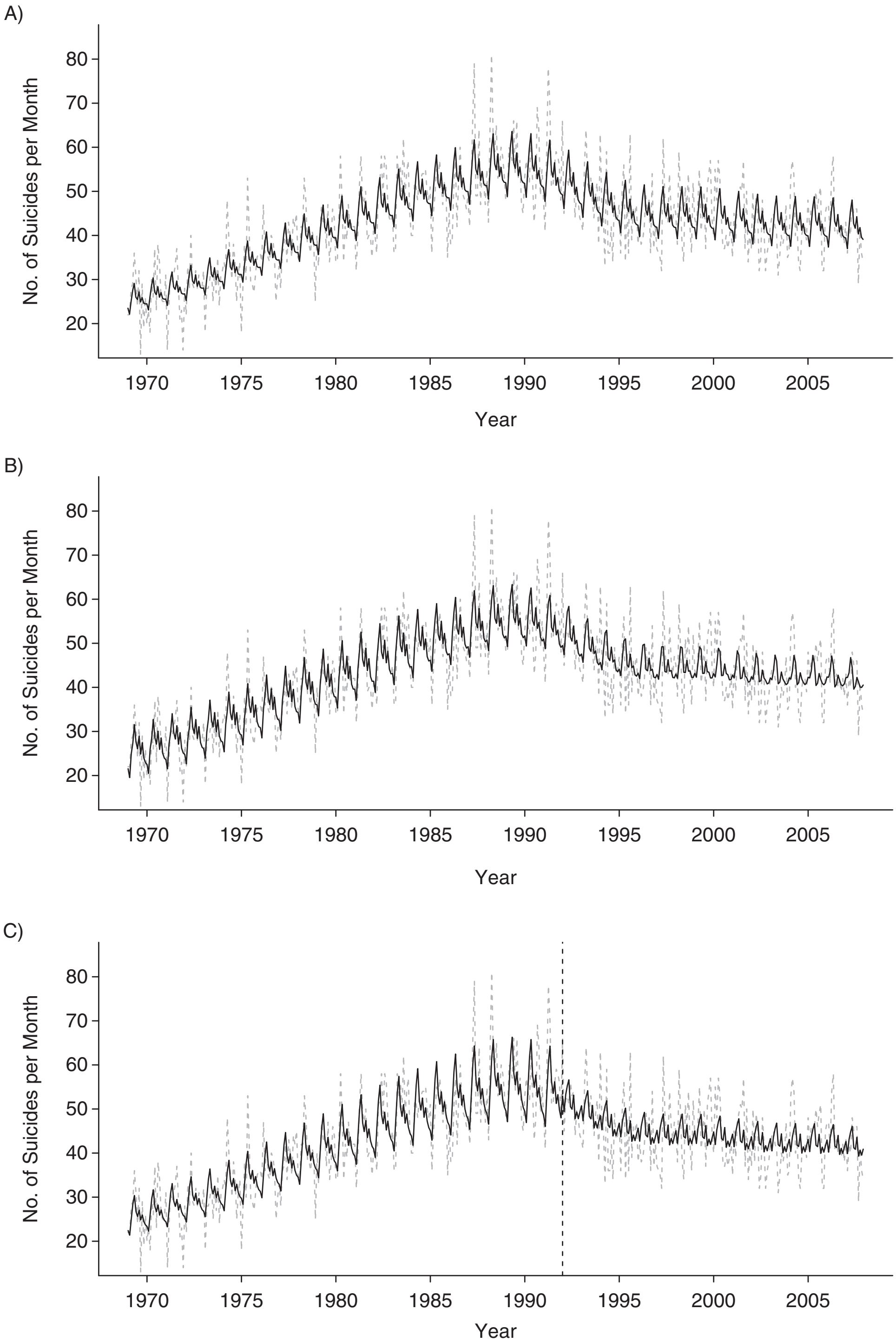

Figure 3. Original data on suicide in Norway during 1969–2007 (gray lines), fitted with 3 models (black lines): A) a generalized additive model (GAM) with added seasonal components modeled by a Fourier series (model 2); B) a GAM with seasonal components assumed to decrease linearly over time (model 3a); and C) a GAM with seasonal components modeled according to a change-point model (model 3b).

Here $I(e)$ denotes the indicator function taking the value 1 if the event e holds true and zero otherwise. The optimal change point t_γ was estimated by fitting model 3b for all possible $t_\gamma = 1, 13, 25, \ldots, 457$, and selecting the best model.

Model comparison

To select the sine and cosine terms to include in the final model(s) optimally describing the seasonal components in

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models 2–3b, we used Akaike's Information Criterion (AIC) (42). AIC is a weighting between parsimony and model fit to the data and is an objective measure of the "goodness of fit" of a model. Note that it is not the absolute value of AIC which is important but the relative values between models, particularly the AIC differences $\Delta_i = \text{AIC}_i - \text{AIC}_{\text{min}}$ (43). The model estimated to be the best has $\Delta_i \equiv \Delta_{\text{min}} \equiv 0$. Models with $\Delta_i >$ 10 relative to the best model have essentially no support in the data, while models with $0 \leq \Delta_i \leq 2$ have substantial support (43).

The 3 additive Fourier Poisson time-series regression models (equations 2–3b) were also compared using AIC, as well as being formally tested against one another using analysis of variance (ANOVA).

RESULTS

Monthly aggregated suicide counts for the whole time period along with the estimated long-term trend (model 1) are shown in Figure 1, along with monthly aggregated suicide rates. The long-term trend is clearly nonlinear, increasing at first and reaching a peak around 1990 before decreasing and stabilizing at a constant level from about 1995 onward. The suicide rates are structurally almost indistinguishable from the suicide counts (Figure 1).

Fitting a seasonal additive Fourier Poisson time-series regression model (model 2) to the full data set, we found significant seasonality, as the model which assumed constant seasonality (model 2) outperformed a model without seasonality (model 1), both in terms of AIC and in formal testing by ANOVA (Table 1). The estimated temporal seasonal mean across the whole 39-year period had an overall peak in May and an overall low in February (Figure 2). Note that since the Poisson model scales with level, the shape of the estimated seasonal pattern is the same throughout the study period, but the magnitude will change, depending on the level of the long-term average (Figure 2). We then fitted a seasonal additive Fourier Poisson time-series regression model with an interaction term (model 3a) and with a change point (model 3b) to the full data set. AICs for the 3 models were 3,066.3 (model 2), 3,055.0 (model 3a), and 3,050.5 (model 3b), respectively. The models with decreasing seasonality (model 3a) and a change point (model 3b) had markedly lower AICs than the model assuming constant seasonality (model 2) to the extent that there was essentially no support in the data for the model with a constant seasonal pattern over time. Model 2 was also rejected when we performed a formal statistical ANOVA test ($P < 0.001$ in comparison with both model 3a and model 3b). Table 1 shows the model comparison results. The model fits for the 3 models are shown in Figure 3. The optimal change point in model 3b was estimated to be the year 1992.

The data set in our study was divided into 4 subgroups by sex and method (male/female and violent/nonviolent) (Figure 4). Notably, violent and nonviolent suicides had different long-term trends over time. The long-term trend in violent suicides has been decreasing since the 1990s, and still is. Nonviolent suicides, after a decrease in the 1990s, have been on the increase since the turn of the millennium. Because violent suicides represent the majority of cases, this curve obviously resembles the curve for the full data set.

We then fitted seasonality models (models 2, 3a, and 3b) for each of the 4 subgroups (Table 1). Significant seasonality was present in all subgroups, as the model assuming constant seasonality (model 2) outperformed a model without seasonality (model 1), both in terms of AIC and in formal testing by ANOVA for all subgroups. The 2 models with decreasing seasonality had better fits than the model with constant seasonality for all subgroups in terms of both AIC and ANOVA. For both groups of female suicides (violent and nonviolent), both model 3a and model 3b performed better than a model assuming constant seasonality (model 2). For male suicides, the model with linearly decreasing seasonality (model 3a) performed better among nonviolent suicides and the model with a change point (model 3b) was better for violent suicides. The change-point model (model 3b) was thus better in 3 out of 4 subgroups compared with the model with constant seasonality (model 2), and the model with linearly decreasing seasonality (model 3a) also performed better in 3 out of 4 subgroups.

DISCUSSION

In this investigation of Norwegian monthly suicide counts from 1969 to 2007, there was a general increase in the number of suicides from 1969 to 1989. From 1990 onwards, there were some years with declining numbers of suicides, with a leveling off from around 1995 onward. There was a significant seasonal component present during the whole period (1969–2007), and using additive Fourier Poisson time-series regression models, we found a statistically significant decrease in this seasonal component throughout the study period, significantly outperforming a model assuming constant seasonality. Seasonality was present in all subgroups of suicides we evaluated, both male/female suicides and violent/nonviolent suicides, with a statistically significant decrease in seasonality for most subgroups.

Seasonality was present when we examined all suicides grouped together. This study adds to the large amount of evidence that such seasonality is present. We also found a significant decrease in seasonality in suicide over the study period. Our investigation thus confirmed what has been suggested by several other researchers (44–46), providing support for the claim put forward by Ajdacic-Gross et al. (6) that seasonality of suicide is in fact a declining phenomenon. The statistical method is based on using trigonometric functions (i.e., sines and cosines) to model seasonality, in combination with the generalized additive modeling framework for modeling continuous nonlinear long-term temporal change. For the fitting of the temporal seasonality component, we had 39 years, that is, repetitions of a full monthly cycle. The modeling suggested that 2 different approaches to changes in seasonality are almost equally plausible: either 1) a steady decrease in seasonality over time or 2) a change point around 1992. However, even with a time series covering 39 years, this study did not have sufficient statistical power to test a model consisting of a combination of these 2 models.

This study also demonstrated that seasonality was present in all 4 of the subgroups considered and is not a phenomenon attributable exclusively to male suicides (8, 9) or violent suicides (3–5). The low monthly counts in some subgroups (e.g.,

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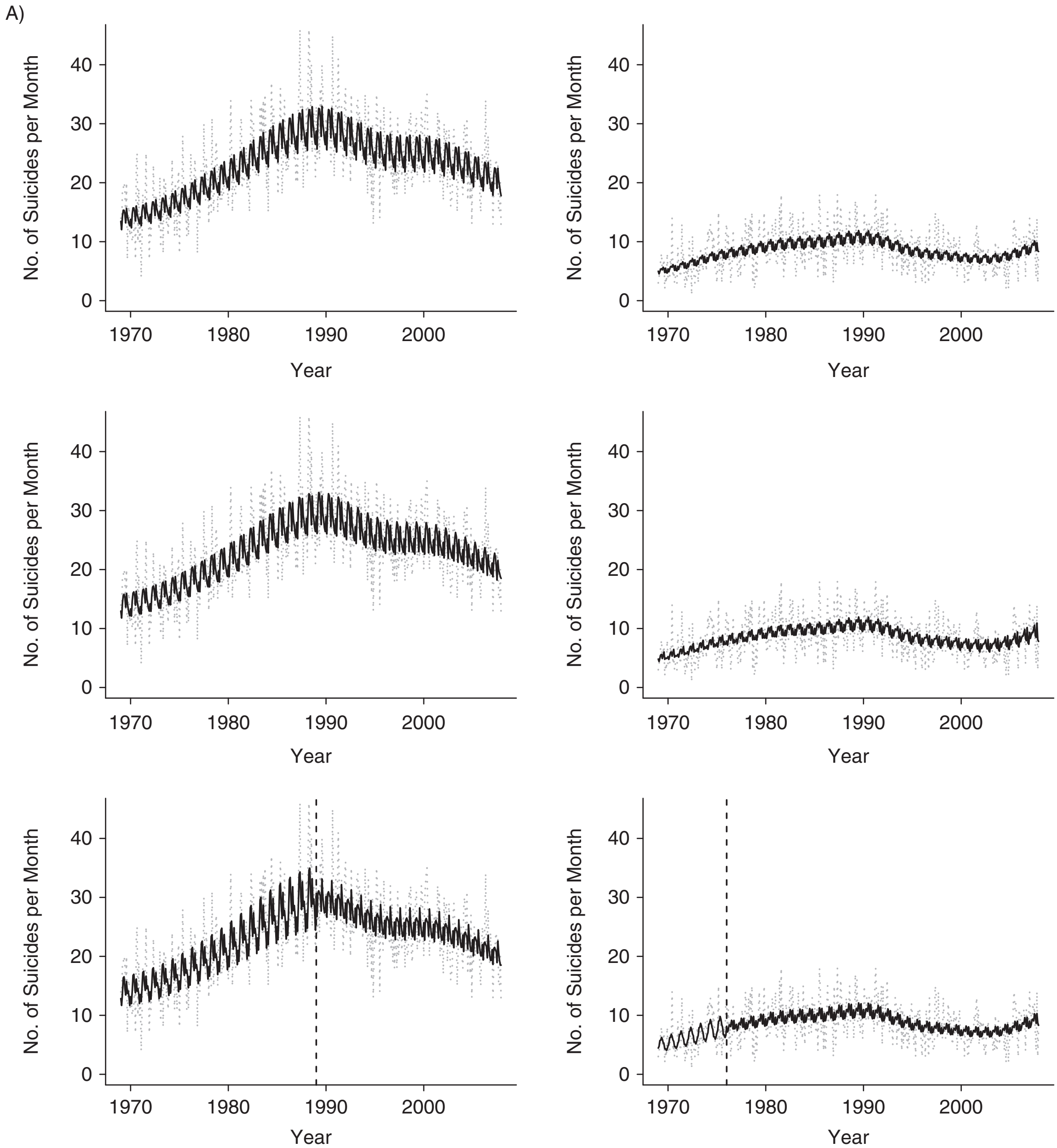

Figure 4 continues

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nonviolent male suicides, violent and nonviolent female suicides with monthly counts around 5–10) imply that only relatively simple models for the seasonal patterns can be fitted, and there is greater uncertainty in parameter estimates. In comparison, models for violent male suicides (monthly counts around 15–30) can be more complex and have less uncertain parameter estimates. However, for all subgroups, a model with change in seasonality over time outperforms the model without change. The results from linearly decreasing seasonality and the varying estimated location of the change point indicate that the change in seasonality over time is probably more complex than either of these two models. However, as for the data set as a whole, the data in these subgroups were insufficient (too low counts and too short a time span) for exploring more intricate changes over time.

Explanations for the seasonality in suicides have been sought by identifying groups which show high seasonality within the suicide rates, such as alcohol dependents (13), psychiatric patients, especially patients with mood disorders (14–17), and patients with allergies and asthma (18). Several other explanations have also been offered (19). Our investigation does not provide evidence as to *why* the observed

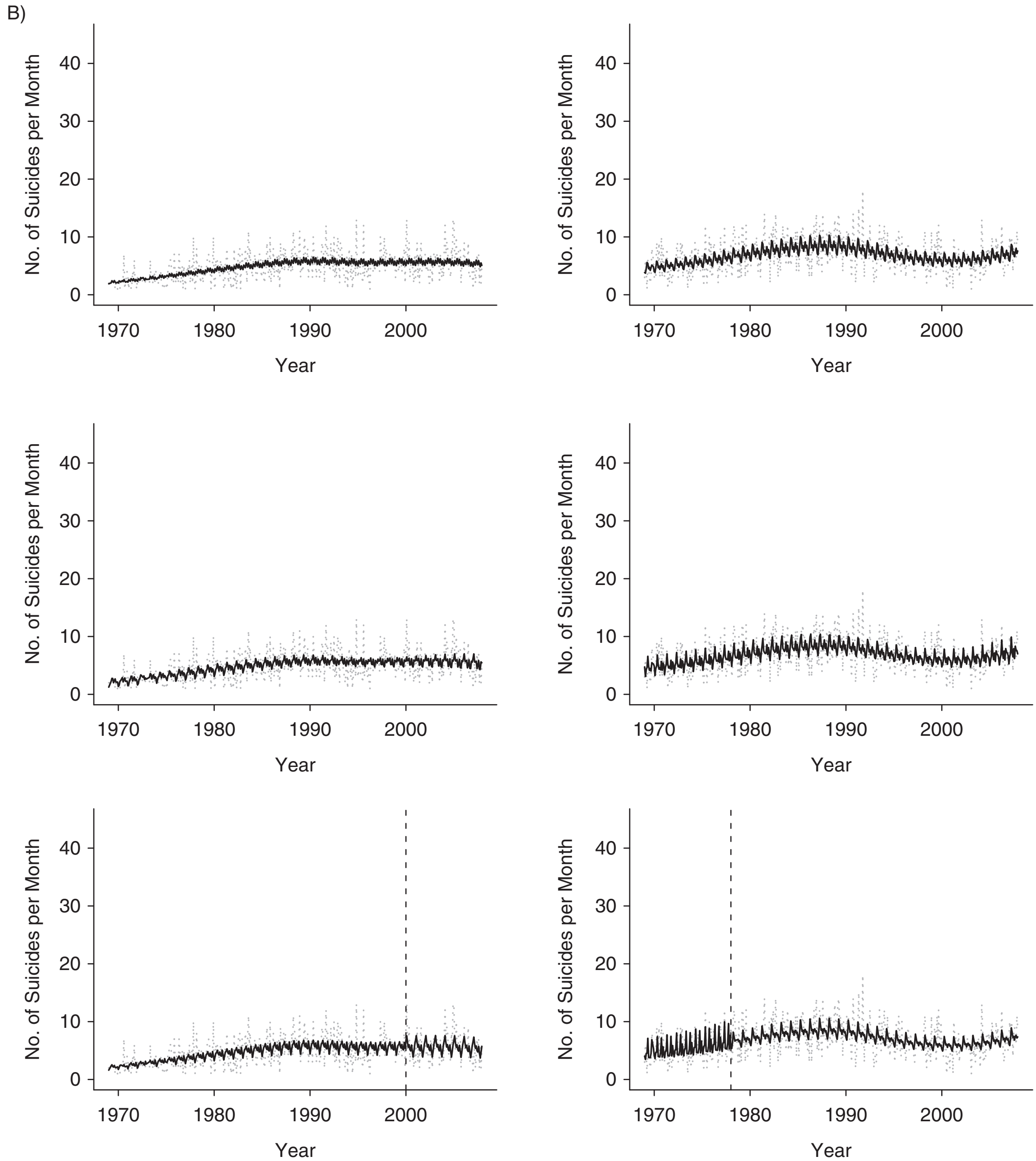

Figure 4. Monthly suicide counts (gray lines) among men (A) and women (B) in Norway, by method of suicide (left column, violent; right column, nonviolent), 1969–2007. The suicide counts were fitted with 3 models (black lines): The top row shows model fit assuming constant seasonality (model 2), the second row shows model fit assuming linearly changing seasonality (model 3a), and the third row shows model fit assuming a change-point model for seasonality (model 3b).

seasonality is present or why indeed this seasonal pattern seems to be diminishing. However, we will suggest some possible explanations.

During the 39 years covered by this study (1969–2007), Norwegian society experienced increasing urbanization and a reduction in the number of people engaged in agricultural production. Young adults, especially, moved from rural areas to the cities, and women were increasingly included in the workforce. A decline in seasonality could be a result of a lowering population in rural areas, offering support to Durkheim's old theory that seasonality is more a rural phenomenon (1, 2, 10).

Seasonality is more pronounced among patients with alcohol use disorders (13). However, during the study period, with declining seasonality, there was a major increase in the use of alcohol in Norway (47). Even if we cannot equate the increase in alcohol use with development of the prevalence

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of alcohol use disorders, it is generally acknowledged that problematic use of alcohol is related to the total consumption of alcohol in a population (48), thus indicating that our present results cannot support a relationship between seasonality and alcohol use. Indeed, earlier we questioned the popular hypothesis of a relationship between alcohol use and suicide rates in different countries (49), finding that self-reported mental health is a better predictor of future suicide (50). Taking the results of our study into consideration, we might have an additional piece of evidence pointing away from changes in total alcohol consumption as an explanatory factor for changes in suicide rates in a country with rather low alcohol consumption like Norway.

The health-care system developed extensively in Norway, as in most other Western countries, during the observation period. This was especially true for the psychiatric health-care system and for the treatment of depression and other psychiatric disorders in general practice. Many more people were reached towards the end of the period. From the 1980s onward, outpatient treatment for psychiatric disorders gradually developed. Better availability of psychiatric treatment could explain both the stabilization in the number of suicides and the concurrent reduction in the seasonality of suicides from around 1990 onward. In addition, the enormous increase in the treatment of depression (via the newly discovered selective serotonin reuptake inhibitors) from the early 1990s onward most likely led to a decrease in suicide rates (51, 52). Because seasonality of suicides may be more pronounced among depressed patients (14, 15), it might be that the observed decline in seasonality is explained by the same factors as the general decline in long-term suicide rates, namely better treatment of depression. This could also explain why the seasonality in female suicides has been affected more than seasonality in male suicides, as women are more likely to be treated for depression than men (53), but it does not explain why the seasonality of violent suicides is affected more than the seasonality of nonviolent suicides, except that violent suicides are more prevalent and thus changes are easier to detect.

During the 39-year observation period, there were major improvements in the treatment of asthma and allergies in Norway, after the introduction of modern pharmacotherapeutic agents. In light of the possible association between seasonality of suicides and allergies (18, 19), the seasonality of immunological factors (23), the novel findings on the relationship between suicide risk and air pollen counts (54), and the strong link between major depression and changes in immunology (55), it would be worthwhile to pursue this area of research to investigate possible connections between immunology, depression, and suicidal behavior.

A limitation in all studies of suicide is the possibility of incomplete registration. However, it is more likely that this would affect the total number of reported suicides over longer periods of time rather than seasonal variations. Another limitation in studies of seasonal variations is that suicides tend to be reported as monthly or seasonal frequencies. Important changes that come in the middle of a month would then not be detected. However, because our main aim was the exploration of a possible decrease in seasonality, not details of the seasonal pattern itself, this was of lesser concern here. Note that the statistical method explored here would work equally well on weekly or even daily suicide counts.

Further subgroup analyses including factors like age and urbanity could have provided more in-depth information. However, despite the long time series as compared with other, similar studies and the complete capture of data on suicides in Norway, the numbers were too small to allow for further subgroup analyses. Finally, we analyzed the Norwegian population; we do not know whether our analytical results are representative of other countries where a decline in the seasonality of suicides has also been suggested (6).

Strengths of our study include the fact that all suicides were reported to Statistics Norway, covering the whole country, ensuring completeness of data. Norway has a reliable public health-care and juridical system, and the quality of the Cause of Death Register is generally believed to be good (56). We believe, therefore, that this study adds to knowledge about the seasonality of suicides, demonstrating—with the use of a statistical model specifically developed for the task—that seasonality of suicides is a declining phenomenon with a marked downward change in the beginning of the 1990s. The suggested additive Fourier Poisson time-series regression model would also be appropriate for studying other temporal phenomena with a seasonal component, such as infectious diseases (57, 58), cardiovascular diseases (59, 60), cancer (61), psychiatric disorders (62, 63), and other phenomena.

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Author affiliations: Norwegian Centre for Addiction Research, University of Oslo, Oslo, Norway (Jørgen G. Bramness, Jo Røislien); National Centre for Suicide Research and Prevention, University of Oslo, Oslo, Norway (Fredrik A. Walby); Department of Psychiatry, Diakonhjemmet Hospital, Oslo, Norway (Fredrik A. Walby); Department of Psychiatry, St. Olav University Hospital, Trondheim, Norway (Gunnar Morken); Department of Neuroscience, Norwegian University of Science and Technology, Trondheim, Norway (Gunnar Morken); and Department of Biostatistics, University of Oslo, Oslo, Norway (Jo Røislien).

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