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Original Article

Falling in the elderly: Do statistical models matter for performance criteria of fall prediction? Results from two large population-based studies

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ABSTRACT

Objective: To compare performance criteria (i.e., sensitivity, specificity, positive predictive value, negative predictive value, area under receiver operating characteristic curve and accuracy) of linear and non-linear statistical models for fall risk in older community-dwellers.

Methods: Participants were recruited in two large population-based studies, “Prévention des Chutes, Réseau 4” (PCR4, $n = 1760$, cross-sectional design, retrospective collection of falls) and "Prévention des Chutes Personnes Agées" (PCPA, $n = 1765$, cohort design, prospective collection of falls). Six linear statistical models (i.e., logistic regression, discriminant analysis, Bayes network algorithm, decision tree, random forest, boosted trees), three non-linear statistical models corresponding to artificial neural networks (multilayer perceptron, genetic algorithm and neuroevolution of augmenting topologies [NEAT]) and the adaptive neuro fuzzy interference system (ANFIS) were used. Falls ≥1 characterizing fallers and falls ≥2 characterizing recurrent fallers were used as outcomes. Data of studies were analyzed separately and together.

Results: NEAT and ANFIS had better performance criteria compared to other models. The highest performance criteria were reported with NEAT when using PCR4 database and falls ≥1, and with both NEAT and ANFIS when pooling data together and using falls ≥2. However, sensitivity and specificity were unbalanced. Sensitivity was higher than specificity when identifying fallers, whereas the converse was found when predicting recurrent fallers.

Conclusions: Our results showed that NEAT and ANFIS were non-linear statistical models with the best performance criteria for the prediction of falls but their sensitivity and specificity were unbalanced, underscoring that models should be used respectively for the screening of fallers and the diagnosis of recurrent fallers.
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1. Introduction

To date, there has not been an effective model to predict falls in the elderly. The performance criteria of previously described models (i.e., sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), area under receiver operating characteristic curve [AUROC] and accuracy [ACC]) have not been useful measures of fall risks, and additionally, this has led to misclassification of fallers [1–4]. Numerous efforts have been made to improve the prediction of falls in the elderly because accurate identification of fallers may have a significant positive impact on the implementation of adapted interventions [1]. In particular, the past decade has been characterized by the development of devices and sensors that allow for accurate measurements of objective body movements [4–7]. These devices are particularly

Abbreviations: ACC, Accuracy; AI, Artificial intelligence; ANFIS, Adaptive neuro fuzzy interference system; ANNS, Artificial neural networks; AUROC, Area under receiver operating characteristic curve; CHAID, Chi-squared automatic interaction detector; MLP, Multilayer perceptron; MICE, Multivariate imputation via chained equations; NPV, Negative predictive value; ANOVA, One-way analysis of variance; PCR4, Prévention des chutes réseau 4; PCPA, Prévention des chutes personnes âgées; PPV, Positive predictive value.

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beneficial for assessing the risks of falls because gait and balance disorders are consistently identified as key risk factors for falls in the elderly [1,4]. Furthermore, they provide accurate measurements of body movements, and they can be easily implemented into clinical practice [1,4–7]. Recently, a systematic review of fall risk assessment in geriatric populations using inertial sensors highlighted that performance criteria of fall prediction could be influenced by the type of statistical models used [4]. This review demonstrated that artificial neural networks (ANNs) were superior at classifying fallers and non-fallers compared to classical linear statistical methods such as binary regression, discriminant analysis or decision tree [4]. Moreover, other efficient models of fall predictions have recently been described in the literature. One such model is called 'neuroevolution of augmenting topologies' (NEAT) [8]. This model is an ANN that used a set of clinical characteristics, which corresponded to the most commonly reported risk factors for falling in the elderly. It has been described as a useful ANN for its ability to identify recurrent fallers in older community-dwellers [8]. These results suggest that ANNs have the potential to improve the performance criteria of the tools designed for fall prediction.

ANNs are an artificial intelligence (AI) technique that emulates human intelligence into computer technology [8,10–12]. Currently, AI may play a role in its potential to support the decision-making process of physicians in several ways. First, AI is relatively applicable in clinical situations because of the ease of accessibility and the implementation of digitalized medicine. Therefore, the integration of AI tools, such as software with AI algorithms in everyday clinical situations, could improve diagnostic accuracy and avoid costs by minimizing the potential for misdiagnosis. Second, predictive AI algorithms based on data-driven models represent an individualized form of practice-based evidence that is drawn from a live population. This improves the potential for personalized clinical decision-making capabilities. Third, AI is more useful when compared to linear models because it has the ability to transform itself into "real world" situations. Finally, AI models are advantageous to linear models because of their ability to deal with a large amount of data and input variables when the specific functional relationship between a dependent variable and an independent variable is unknown.

Falling is a complex event that involves numerous interacting factors [1–3,8]. Because ANNs apply non-linear statistics to pattern recognition, they are especially useful in their potential to predict a chaotic event such as fall [8,9]. However, they have not been routinely applied to predict fall risks. Furthermore, the studies that have applied ANNs as predictors of falling have demonstrated mixed results [8,10–12]. Two studies using a retrospective collection of falls combined with a physical assessment using body inertial sensors reported that ANNs correctly identified fallers with a high specificity, sensitivity, and accuracy above 88% [10,12]. In contrast, results from ANNs using clinical characteristics were more contrasted, as one study showed great performance for fall prediction [8], while the other did not [11]. This divergence could be due to the study design (i.e., retrospective or prospective), the number of falls occurring during the follow-up, or the amount of data available for analysis, which should be considered when using ANNs for analyses. The amount of clinical data that is applicable is usually less than that provided by body inertial sensors, which questions the ability of ANNs to provide accurate information on fall prediction when using individuals' clinical characteristics.

Over ANNs, other AI techniques have been studied as models to predict clinical events [13]. One of the most powerful among these AI techniques is the fuzzy logic, which combines a clustering algorithm and fuzzy system identification [13–15]. Fuzzy logic is superior to other AI systems [15] and it improves the performance criteria of [15]. Fuzzy models have applied in different clinical scenarios, particularly for diagnostic purposes [16,17]. However, to the best of our knowledge, this superior form of AI has not yet been used as a model to predict falls in the elderly.

In order to improve and individualize the prediction of falls for specificity, it is imperative to compare the performance criteria (i.e., sensitivity, specificity, PPV, NPV, AUROC and ACC) of linear and non-linear statistical models that have been used previously in the literature. ANNs and fuzzy logic are advantageous models that can be used to predict chaotic events like falls because large databases are nowadays easily accessible. We hypothesized that these non-linear models of AI would be superior to linear models at predicting falls in older adults. We had the opportunity to test this hypothesis in two large representative French population-based studies ("Prévention des Chutes, Réseau 4" [PCR4] and "Prévention des Chutes Personnes Agées" [PCPA];18,19). The aim of this study was to compare the performance criteria (i.e., sensitivity, specificity, PPV, NPV, AUROC and ACC) of linear statistical models (i.e., binary regression, discriminant analysis, Bayes network algorithm, decision tree Chi-squared automatic interaction detector [CHAID] algorithm, random forest and boosted trees) and non-linear statistical models corresponding to three ANNs (multilayer perceptron [MLP], genetic algorithm and NEAT) and the adaptive neuro fuzzy interference system (ANFIS) for fall risk in participants recruited in PRC4 and PCPA studies.

2. Materials and methods

2.1. Participants

Both PCR4 and PCPA studies have collected the same clinical variables and were performed in older community-dwellers living in the same French area. However, the two studies differed in their participant recruitment. Sampling and data collection procedures of the PCR4 and PCPA studies have been described elsewhere in detail [18,19]. In summary, PCR4 was a cross-sectional study with retrospective data collection of history of previous falls during the past 12 months of inclusion [18]. Between January 2007 and June 2008, 1760 community-dwelling volunteers aged 65 and older were recruited, in 8 health examination centers (HEC) for the French health insurance localized in Eastern France, during a free medical examination. Participants were excluded if they had the following criteria: acute medical illness in the past 3 months; neurological diseases (Parkinson's disease, cerebellar disease, myelopathy, peripheral neuropathy); major orthopedic diagnoses involving the lumbar vertebra, pelvis or lower extremities. PCPA was an observational cohort study with prospective data collection on falls during a 12-month follow-up period [19]. Between January 2007 and May 2007, 1765 community-dwelling volunteers aged 65 and older were recruited in 10 HEC during a free medical examination. Participants were excluded if they had the following criteria: living in nursing home; neurological disease (dementia, Parkinson's disease, cerebellar disease, myelopathy, peripheral neuropathy); and unable to understand French or follow simple commands. Both studies used the same definition of fall, which was defined as unintentionally coming to rest on the ground, floor, or other lower level [1]. Thus, falls resulting from acute medical events and/or external force were excluded from the analysis. The date, number, features, and consequences of falls were also asked using a standardized questionnaire [18–20]. Missing data were imputed applying the multivariate imputation via chained equations (MICE) method [21,22].

2.2. Clinical assessment

All participants underwent a full medical examination. Age (mean age and standard deviation, and a categorization in two groups based on the cut-off value of 75 years), marital status (i.e., married or widower) and sex were recorded. Body mass index (BMI, in kg/m^2) was calculated based on anthropometric measurements (i.e., weight in kilograms, and height in meters). The number of drugs daily taken and the use of psychoactive drugs (i.e., benzodiazepines, antidepressants or neuroleptics) were noted. Use of biphosphonates, calcium and vitamin D supplements

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