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Original Study

Artificial Neural Network and Falls in Community-Dwellers: A New Approach to Identify the Risk of Recurrent Falling?

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Keywords: Recurrent fall, elderly, artificial neural network

Abstract

Background: Identification of the risk of recurrent falls is complex in older adults. The aim of this study was to examine the efficiency of 3 artificial neural networks (ANNs: multilayer perceptron [MLP], modified MLP, and neuroevolution of augmenting topologies [NEAT]) for the classification of recurrent fallers and nonrecurrent fallers using a set of clinical characteristics corresponding to risk factors of falls measured among community-dwelling older adults.

Methods: Based on a cross-sectional design, 3289 community-dwelling volunteers aged 65 and older were recruited. Age, gender, body mass index (BMI), number of drugs daily taken, use of psychoactive drugs, diphasphonate, calcium, vitamin D supplements and walking aid, fear of falling, distance vision score, Timed Up and Go (TUG) score, lower-limb proprioception, handgrip strength, depressive symptoms, cognitive disorders, and history of falls were recorded. Participants were separated into 2 groups based on the number of falls that occurred over the past year: 0 or 1 fall and 2 or more falls. In addition, total population was separated into training and testing subgroups for ANN analysis.

Results: Among 3289 participants, 18.9\% (n = 622) were recurrent fallers. NEAT, using 15 clinical characteristics (ie, use of walking aid, fear of falling, use of calcium, depression, use of vitamin D supplements, female, cognitive disorders, BMI <21 kg/m\textsuperscript{2}, number of drugs daily taken >4, vision score <8, use of psychoactive drugs, lower-limb proprioception score \textless{} 5, TUG score >9 seconds, handgrip strength score \textless{} 29 (N), and age \textgtr{} 75 years), showed the best efficiency for identification of recurrent fallers, sensitivity (80.42\%), specificity (92.54\%), positive predictive value (84.38\%), negative predictive value (90.34\%), accuracy (88.39\%), and Cohen k (0.74), compared with MLP and modified MLP.

Conclusions: NEAT, using a set of 15 clinical characteristics, was an efficient ANN for the identification of recurrent fallers in older community-dwellers.

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Recurrent falling, defined as 2 or more falls in a 12-month period, is highly prevalent among adults aged 65 years and older, with prevalence estimated at approximately 25\%. Recurrent falls lead to injuries, hospitalization, loss of independence, and social disability, which impose high costs to public health and social services.\textsuperscript{1-3} Identification of recurrent fallers, which is the first step of falls-prevention strategies in older community-dwellers, is therefore crucial for their efficiency and cost-effectiveness.\textsuperscript{1,4}

There are complex interactions between host-related motor behaviors and environmental characteristics for the mechanism of falls.\textsuperscript{3,5} Due to the interplay between risk factors of falls, the prediction of falls recurrence remains difficult and depends on combinations of risk factors of falls. This suggests that recurrent falls are the manifestation of chaotic motor behaviors that have been thus far poorly understood by the classical linear statistical methods.
previously used for the identification of recurrent fallers. Exploring new statistical methods to improve the identification of recurrent fallers is an objective to reach.

There are uncertainties on the importance of risk factors of recurrent falls and/or their combinations. First, there are numerous assessment tools exploring the risk of falls in the literature based on classical linear statistical methods, but their validation and usefulness remain obscure. Second, identification of recurrent fallers using linear models assumes that data belong to the Bayesian models (ie, normal distribution) and that there is a linear association of each variable with recurrent falls. The main obstacle with this approach is that these models are invalidated when this assumption is disturbed. Furthermore, only a limited number of risk factors of falls can be explored with linear models, which leads to exclusion of potential variables influencing them and resulting in low power of identification of individuals at risk of recurrent falls. Third, many traditional statistical methods do not learn incrementally as new input data arrive.

Artificial neural networks (ANNs) are data analysis tools that have been developed to overcome limitations of linear models. ANNs are computational models that are capable of machine learning and pattern recognition. Because they apply nonlinear statistics to pattern recognition, ANNs are particularly adapted to a “chaotic” mechanism of recurrent falls. Inspired by animals’ brains, they are usually presented as interconnected systems that are organized in several layers. These layers are made up of a number of interconnected nodes that contain activation function. Data are presented to the network via the input layer, which communicates to one or more hidden layers where the processing is done via a system of weighted connections. In final, the hidden layers are related to an output layer that provides the result.

Now, the advance of ANNs, combined with improvement of computer technology, offers new possibilities for useful and wide application of ANNs as diagnostic support aids for physicians who must make the best decision for their patients. ANNs have already been used for the identification of several adverse health events, such as myocardial infarction or cancer and prediction of length of stay. Few studies have used them to determine the risk of falls. These studies showed mixed results, as some reported a high efficiency for falls prediction but others did not, suggesting that ANNs required a specific development to improve their efficiency in terms of identification of risk of falls. Furthermore, these previous studies did not examine specifically the identification of recurrent fallers.

Multilayer perceptron (MLP) is one of the most well-known ANNs. By developing specific ANNs devoted to the identification of risk of recurrent falls, such as the modified MLP and the NEAT (neuroevolution of augmenting topologies), we hypothesized that these ANNs could identify recurrent and nonrecurrent fallers with great efficiency. More precisely, we suggested that by analyzing a set of clinical characteristics corresponding to risk factors of falls among older recurrent and nonrecurrent fallers, they could select variables that form the best combination for identifying the risk of falls in older community-dwellers. A large amount of input data is required by ANNs to provide valid results. We had access to a database composed of a large sample of French older community-dwellers in which the information on the occurrence of falls over the past year was recorded during a full clinical assessment screening; specifically, the main risk factors of falls in older adults, making it possible to test our research hypothesis. The aim of this study was to examine the efficiency of 3 ANNs (ie, MLP, modified MLP, and NEAT) for the classification of recurrent fallers and nonrecurrent fallers using a set of clinical characteristics measured among community-dwelling older adults.

Methods

Participants

Between July 17, 2008, and January 12, 2010, 3289 community-dwelling volunteers aged 65 and older were recruited during a free medical examination in the Health Examination Centers of the French health insurance of Lyon, France. They were included in the “Prévention des Chutes, Réseau 4” study, which was based on a cross-sectional design with retrospective data collection of history of falls during the past 12 months. Exclusion criteria were acute medical illness in the past 3 months, and inability to understand and speak French. Of the 3289 recruited participants during the inclusion period, full data were available for 3289 participants (100%) and were used in the analyses.

Clinical Assessment

Participants underwent a full medical examination. Age (categorized into 2 groups based on the cutoff value of 75 years) and gender were recorded. Body mass index (BMI, in kg/m²) was calculated based on anthropometric measurements (ie, weight in kg, and height in m). The number of drugs taken daily and the use of psychoactive drugs, including benzodiazepines, antidepressants, or neuroleptics, were recorded. Use of diphosphonate, calcium, and vitamin D supplements also was noted from the primary care physician’s prescription, whatever the dosage schedule or route of administration and regardless of the date of commencement. Regular use of walking aid was recorded, and fear of falling (FOF) was assessed using a single question: “Are you afraid of falling?” with a binary answer (ie, yes versus no). Distance binocular vision was measured at 5 m with a standard Monoyer letter chart. Vision was assessed while wearing corrective lenses, if usually used by the participant. Basic mobility was assessed with the Timed Up and Go (TUG) test. Lower-limb proprioception was evaluated with a 64-Hz graduated tuning fork placed on the tibial tuberosity and scored from 0 (worst) to 8 (best). The mean value obtained for the left and right sides was used in the present data analysis. The maximal isometric voluntary contraction (MVC) strength of handgrip was measured with computerized hydraulic dynamometers (Martin Vigorimeter; Medizin Tecnik, Tutlingen, Germany). The test was performed once on each side. The highest MVC value recorded was used in the present analysis. Depression was evaluated with the 4-item Geriatric Depression Scale (GDS) score. A score greater than or equal to 1 indicated the presence of depressive symptoms. Cognitive disorders were defined by an abnormal clock-drawing test (CDT). We selected a limited number of risk factors for falling (n = 16) in our study because they are the most commonly reported risks in the literature and because they were easily recordable during a free medical examination.

The participants also were interviewed using a standardized questionnaire, gathering information on the history of falls over the past year. This face-to-face interview was based on 22 standardized questions exploring the number, delay, and place of falls (ie, inside or outside the participant’s house); the evoked causes and circumstances of falls (ie, syncope or other acute medical event, body transfer from sit position, walking, or other physical activities such as cycling) and all physical traumatisms; and inability to get up from ground after a fall. A fall was defined as an event resulting in a person coming to rest unintentionally on the ground or at another lower level, not as the result of a major intrinsic event or an overwhelming hazard. Thus, falls resulting from acute medical events and/or external force were excluded from the analysis. Recurrent falls were defined as 2 or more falls in a 12-month period.
Participants in the study were included after giving their written informed consent for research. The study was conducted in accordance with the ethical standards set forth in the Declaration of Helsinki (1983). The Ethics Committee of Lyon, France, approved the entire study protocol.

Statistical Analysis

Participants’ baseline characteristics were summarized using frequencies and percentages. Participants were separated into 2 groups based on the number of falls reported during the past 12 months: 0 or 1 falls (ie, nonrecurrent fallers) and 2 or more falls (ie, recurrent fallers). Quantitative variables (ie, vision, TUG, lower-limb proprioception, and handgrip strength) were categorized based on the tertilization of their mean values and the percentage of participants in the lowest and intermediate tertiles was presented. Between-group comparisons were performed using the $\chi^2$ test. Description of ANN analysis is provided in Appendix 1 (please see Supplementary Data). The percentage of correct classification of recurrent and nonrecurrent fallers was calculated for each ANN model. The efficiency of each ANN was evaluated using different criteria: sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), the accuracy (ACC), and the Cohen $\kappa$. A Bonferroni adjustment that implies dividing the usual $P$-value threshold set at .05 by the number of comparisons performed was used, here set to 16. Thus, the new $P$-value threshold used was less than .003. All statistics were performed using R 3.1.0 (developed by R Development Core Team; License: GNU General Public License) and NetBeans IDE 8.0 (Oracle Corporation; License: CDDL or GPL2).

Results

Among 3289 included participants, 18.9% ($n = 622$) were recurrent fallers. As shown in Supplementary Table 1, comparisons of characteristics between nonrecurrent and recurrent fallers were significant in most cases ($P < .001$), except for the lower-limb proprioception ($P = .313$), BMI ($P = .178$), and cognitive disorders ($P = .003$). In summary, recurrent fallers were more frequently women, older, with a lower BMI, and took more drugs. They more frequently used a walking aid. They also more frequently had FOF, and lower basic mobility, vision, and handgrip performance. In addition, an abnormal 4-item GDS score was more prevalent in recurrent fallers compared with nonrecurrent fallers.

The combinations of clinical characteristics sorted by their relative importance (ie, strength of association with recurrent falls) are shown in Supplementary Table 2. A total of 14 combinations involving from 16 to 3 clinical characteristics were therefore identified. To obtain this number of combinations, the variable with the lowest value of importance (ie, 0.00) was eliminated step by step. Supplementary Table 3 shows that 4 combinations of variables in MLP (ie, combination of clinical characteristics no. 1, no. 2, no. 3, and no. 4) provided the best classification in terms of recurrent fallers and nonrecurrent fallers. Furthermore with modified MLP, 3 sets of variables (ie, combination of clinical characteristics no. 4, no. 7, and no. 9) also provided a good value in terms of identification. In addition, NEAT showed the best sensitivity (combination of clinical characteristics no. 2 = 80.42%), PPV (combination of clinical characteristics no. 2 = 84.38), NPV (combination of clinical characteristic no. 3 = 90.34), and ACC (combination of clinical characteristics no. 2 = 88.39) compared with MLP and modified MLP (Supplementary Table 3). However, NEAT had the lowest specificity (combination of clinical characteristics no. 2 = 92.54%). As shown in Figure 1, NEAT had the highest value of Cohen $\kappa$ calculated at 0.74 for the combination no. 2. Thus, the best efficiency in terms of identification of recurrent fallers

![Fig. 1. Comparison of Cohen $\kappa$ for recurrent falls prediction with different ANN architectures and different combinations of clinical characteristics (ie, from 16 to 3).](image)
while comparing sensibility, specificity, VPP, VPN, ACC, and Cohen $\kappa$, was shown with NEAT, which correctly classified 2465 of 2667 nonrecurrent fallers and 500 of 622 recurrent fallers while using a combination of 15 of the following baseline characteristics: use of walking aid, FOF, use of calcium, depression, use of vitamin D supplements, female gender, cognitive disorders, BMI lower than 21 kg/m$^2$, number of drugs taken daily at more than 4, distance vision score lower than 8, use of psychoactive drugs, lower-limb proprioception of 5 or lower, TUG score of more than 9 seconds, handgrip strength score of 29 N or lower, and age 75 years or older. Modified MLP using the same combination of characteristics correctly classified 2379 of 2667 nonrecurrent fallers (specificity = 95.7%; PPV = 73.18%), and 292 of 622 recurrent fallers (sensitivity = 50.17%; NPV = 89.13%), whereas MLP using a combination of 13 characteristics (combination n°4, Supplementary Table 2) classified 2345 of 2667 nonrecurrent fallers (specificity = 87.96%; PPV = 46.22%), and 276 of 622 recurrent fallers (sensitivity = 44.37%; NPV = 87.15%).

**Discussion**

Our results show that NEAT and modified MLP are both efficient ANNs for the identification of recurrent fallers, the most effective ANN being NEAT.

A limited number of studies used ANNs to determine the risk of falls. One study used clinical variables, although 2 other studies used quantitative body movement information while performing activities of daily living, from small wearable inertial-sensors-based systems. Like the MLP used in our study, Bath et al showed in a prospective cohort study that an ANN, and more specifically the Genetic algorithm neural networks combining 16 clinical characteristics, was an accurate tool to identify nonfallers with a high level of correct classification calculated at 92%. In addition, and as we reported with MLP, they also found a poor level of accuracy for the detection of fallers with a correct classification rate calculated at only 31%. In contrast, Giansanti et al. published 2 studies using a retrospective collection of falls combined with a physical assessment using body inertial sensors. These authors showed that information from the sensors analyzed with MLP correctly identified fallers with a specificity that ranged from 88 to 97, a sensitivity that ranged from 89.4 to 98.0, and an accuracy that ranged from 88 to 97. Recently, a systematic review of fall-risk assessment in geriatric populations using inertial sensors underscored that ANNs provided the best results in terms of correct classification of fallers. NEAT, used in our study, had the same efficiency as the studies by Giansanti et al. However, compared with these authors, we used combinations of a set of clinical characteristics that are easily measurable compared with body movement measured with inertial sensors.

Risk of falls is usually based on a clinical fall-risk assessment. In their systematic literature review based on Cochrane methodology, Oliver et al reported that only a small number of significant risk factors of falls emerged consistently. This point was confirmed by our study and the study by Bath et al, in which the best combination of clinical characteristics used to identify fallers was composed of, respectively, 15 and 16 characteristics involving information on age, gender, BMI, number and type of drugs taken daily, use of walking aid, FOF, vision and lower-limb proprioception, handgrip strength, basic mobility performance, and depressive symptoms and cognitive performance. Risk assessment tools constructed with similar variables and using classical linear statistical methods have been shown to predict falls with sensitivity and specificity in excess of 70%. In contrast, our study shows for the first time, to the best of our knowledge, that a clinical fall-risk assessment combined with ANN analysis, and more specifically NEAT, have high efficiency in terms of correct classification of recurrent fallers. Currently, ANNs have a clinical impact in different specific medical areas, notably in early detection of acute myocardial infarction. The range of prototypes already reported in the medical literature is evidence of the potential of intelligent medical instruments for multivariate prognostic or diagnostic inference. In the global context of health care as a commodity, a decision supported by ANN is likely to become a necessity rather than an optional extra.

Furthermore, our results showed that recurrent fallers differed from nonrecurrent fallers. Indeed, we reported that female gender, age, polypharmacy, use of psychoactive drugs, abnormal basic mobility, poor vision, muscle weakness, FOF, and depressive symptoms were associated with the recurrence of falls, which is in concordance with previous published studies. Compared with age, the role of female gender in the recurrence of falls remains not yet fully elucidated. It has been suggested that the effects of chronic diseases and physiologic decline could be different between women and men, and, thus, lead to more gait and balance disorders. Similar to our findings, previous studies showed that impaired performance in vision and proprioception were related to falls and their recurrence. In addition, the FOF also has been associated with unsafe gait. In contrast, we reported that low BMI, poor lower-limb proprioception, and cognitive disorders were not associated with the recurrence of falls, which is consistent with previous literature (for proprioception) or could be explained by the low prevalence of denutrition in the studied sample (for BMI) or by the lack of sensitivity of the neuropsychological examination limited to a CDT (for cognitive disorders).

Our study has some limitations. First, the study cohort was restricted to community-dwelling older adults who were probably healthier, more motivated, and also showed greater interest in health issues than the general population of older adults. Second, our findings should take into account the limitation of the study design. The cross-sectional design of the present study may represent a limitation to the exploration of the association between risk factors for falls and their recurrence, compared with a prospective cohort study design. Third, limitations of this study include a potential recall bias, as falls are usually underreported in older adults. Prospective registration systems, shorter recall period, or the use of fall diaries have proven their superiority over other methods of data collection, and could lead to a substantial increase in reported falls. Fourth, another limitation related to the ANN technique may be the problem of overfitting while training ANN. This problem is more important in MLPs trained with backpropagation compared with NEAT. To limit the overfitting effect, we applied data splitting, repeated training/test splits, and weight decay. In addition, the selection of ANNs was based on the degrees of freedom that also aim to prevent overtraining.

To conclude, in our study, we assessed the ability of ANNs to identify recurrent and nonrecurrent fallers by using a set of clinical characteristics corresponding to risk factors of falls recorded during a full medical examination. The results underlined that modified MLP and especially NEAT were effective for the identification of recurrent fallers, whereas MLP is more effective for classification of nonrecurrent fallers. These results seem likely useful for fall-prevention strategies in the general population. The next step should be the comparison of the efficiency of ANNs with classical linear statistical approaches using data from prospective cohort studies.

**Supplementary Data**

Supplementary Data related to this article can be found online at http://dx.doi.org/10.1016/j.jamda.2014.09.013.
References


