NEURONAL NOISE INFLUENCES GAIT VARIABILITY AND FALL RISK IN A DYNAMIC WALKING MODEL

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INTRODUCTION

Older adults are at an increased risk of falling and exhibit increased gait variability [1, 2]. We do not know however if increased gait variability directly causes these falls. Neuronal noise increases with aging are likely to increase gait variability, which in turn might increase fall risk. Conversely, increased variability could reflect *appropriate* corrections for small perturbations and thereby indicated decreased fall risk. Thus, the relation between these factors needs to be better understood.

The aims of this study were to determine how increased neuronal noise affects gait variability and probability of falling, and if changes in gait variability directly predict fall risk. We hypothesized that with increasing neuromuscular noise amplitude 1) probability of falling and 2) gait variability would increase, and that 3) gait variability would significantly predict fall risk.

METHODS

We implemented an intrinsically laterally unstable 3D dynamic walking model (Fig. 1), adapted from [3]. To maintain lateral stability, this model included a lateral step controller. At each instant of ground contact this controller made small lateral adjustments to match the state variables to their ‘noise free solution’ values. The lateral adjustments were achieved by changing the splay angle of the legs (ϕ). The model otherwise walked passively down a gentle slope (4%), with gravity providing the forward propulsion [3].

To approximate the neuronal noise that is present in humans, we applied uniformly distributed random noise to the lateral step controller. The amplitude of this noise (j_{noise}) was varied between a very small amplitude that did not make the model fall over and a large amplitude for which the model always fell. For each condition, 100 simulations were run, each up to 125 steps or until the model fell over.

Fig. 1. Graphical representation of the 3D dynamic walking model.

The probability of falling ($\%_{FALL}$) was calculated for each j_{noise} and also the average number of steps the model took before falling (*STF*). Gait variability measures were calculated for each simulation. Step length (SD_{SL}), step width (SD_{SW}) and step time (SD_{ST}) variability were calculated as their respective standard deviations. Variability of the state variables was calculated for each state variable individually $MSD(q)$ (as in [4]) and combined in a single measure $MSD(\theta_{Tot})$ as the length of the vector containing all state variability measures.

The correlations between the gait variability measures and $\%_{FALL}$ or *STF* were approximated by sigmoidal fits. These sigmoidal fits were calculated using ‘lsqcurvefit' in Matlab (Mathworks, R2008a). For each relationship variance accounted for (r^2) and statistical significance (p) were reported.

RESULTS AND DISCUSSION

The model fell over more often and after fewer steps when noise amplitude (j_{noise}) increased (Fig. 2). This confirmed our first hypothesis. Gait variability increased with j_{noise} in a sigmoidal manner (Fig. 3) and could predict fall risk ($\%_{FALL}$) significantly (Fig. 4). This confirmed our second hypothesis and partly confirmed our third.

The most important outcome from this study was that it showed how changes in gait variability resulting from increased neuronal noise can directly affect fall risk. Gait variability increased with noise amplitude (Fig. 3) and the probability of falling increased in turn with increasing gait variability (Fig. 4).

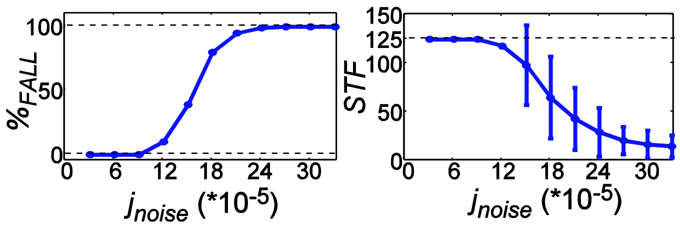

Fig. 2. $\%_{Fall}$ and *STF* against j_{noise}. Error bars represent ±1 standard deviations.

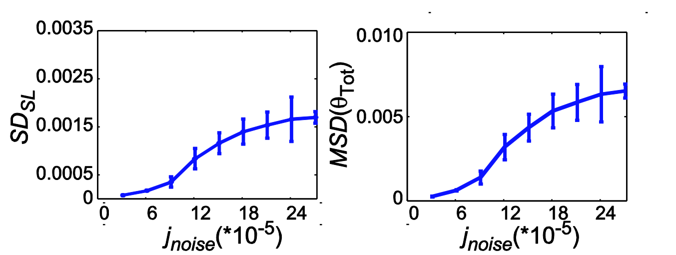

Fig. 3. j_{noise} against the variability in SD_{SL} and $MSD(\theta_{Tot})$. Error bars represent ±1 standard deviation. Similar figures for SD_{SW} and SD_{ST} showed the same trends.

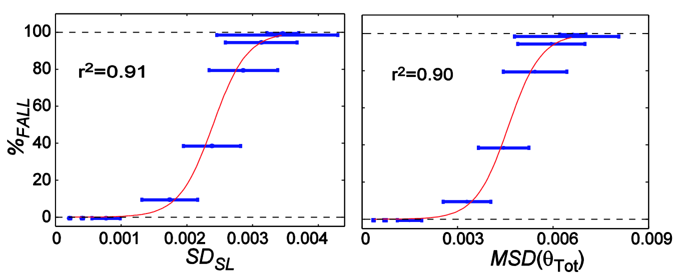

Fig. 4. SD_{SL} and $MSD(\theta_{Tot})$ against $\%_{FALL}$. Red lines are sigmoidal functions fitted to the average data. Error bars represent ±1 standard deviation. All r^2 values were very high ($r^2 \geq 0.87$; $p \leq 2.3*10^{-4}$). Similar figures for SD_{SW} and SD_{ST} showed the same trends and are therefore not shown.

Notably, the relationship between gait variability and the probability of falling was far from linear, as often assumed. At either low gait variability (which might correspond to healthy adults) or high gait variability (which might correspond to frequent fallers), small increases in noise amplitude and variability had only *minor* effects on probability of falling. Conversely, at intermediate noise and gait variability levels (which might correspond to healthy elderly), similar incremental increases resulted in *significant* increases in probability of falling. This is explained as follows. At very low noise amplitudes, the model was well within its limits, whereas at intermediate noise amplitudes, the model got close to its maximum ability to deal successfully with the perturbations applied to the controller. At the very high noise amplitudes the model was already beyond this maximum ability.

We used a very simplified model in this study that was sufficient to address our research aims, but it did not include many other factors that may also contribute to fall risk. The conclusions of our study therefore only relate to fall risk and neuronal noise. We were therefore able to show that there is a direct link between neuronal noise, gait variability and fall risk. The relationship we found between gait variability and fall risk may be specific to this model, however $\%_{FALL}$ has to be bounded between 0% and 100% and therefore some type of sigmoidal relationship has to be exhibited. Whether or not these findings will translate to predicting risk of falling in humans remains to be tested.

CONCLUSIONS

This study validated the concept that age-related increases in neuronal noise are likely to play a direct contributing role in increasing fall risk. Changes in gait variability resulting from increases in neuronal noise may predict fall risk. The relationship found between fall risk and gait variability was however not linear and therefore care needs to be taken when applying gait variability as a predictor in fall prevention practice.

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ACKNOWLEDGEMENTS

Funded by Grant #1-R21-EB007638-01A1 from the National Institutes of Health.