Saccades During Smooth Pursuit in Macular Degeneration

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Introduction

Saccades and smooth pursuit are inextricably linked, particularly in cases of low gain, where saccades can help bring the fovea back on target. Individuals with macular degeneration (MD) have compromised foveas due to central field loss, which impacts both fixation stability and saccades, as well as the interaction between the saccade and pursuit systems. To investigate how saccades associated with pursuit are affected, we conducted a quantitative analysis of binocular smooth pursuit eye movement data collected for aprior study (Shanidze et al., 2017) of smooth pursuit in MD. Here we extend that work by characterizing saccadic intrusions in MD participants during pursuit and pre-pursuit fixation.

Methods

- Examined saccade frequency, magnitude, and direction across viewing conditions
- 7 MD participants 4 control participants

ID	D Eye	Age	Sex	Dx	logMAR Acuity (D)
P1	R	73	M	AMD	1.3
P2	R	52	M	JMD	−0.1
P3	R	71	M	AMD	0.1
P4	R	87	F	AMD	0.7
P5	L	91	M	AMD	0.1
P6	L	84	F	AMD	0.6
P7	R	87	F	AMD	0.2
C1	L	84	F	Control	−0.1
C2	L	70	F	Control	0.0
C3	R	73	F	Control	−0.1
C4	L	74	M	Control	0.1

*Source: Shanidze et al., 2017

- Task: Step ramp paradigm (Rashbass 1961)
  - 1° spot stimulus
  - 6° step, 12° ramp
- 6 directions: 0°, 90°, 135°, 180°, 270°, 315°
- 3 target speeds: 5, 10 & 15 °/s
- Binocular, dominant (better) & nondominant eye viewing
- Binocular eye movement recordings (EyeLink)
- Saccades detected offline during fixation & pursuit
  - Eye velocity > 40°/s or acceleration > 150 °/s
  - Confirmed manually by an experimenter

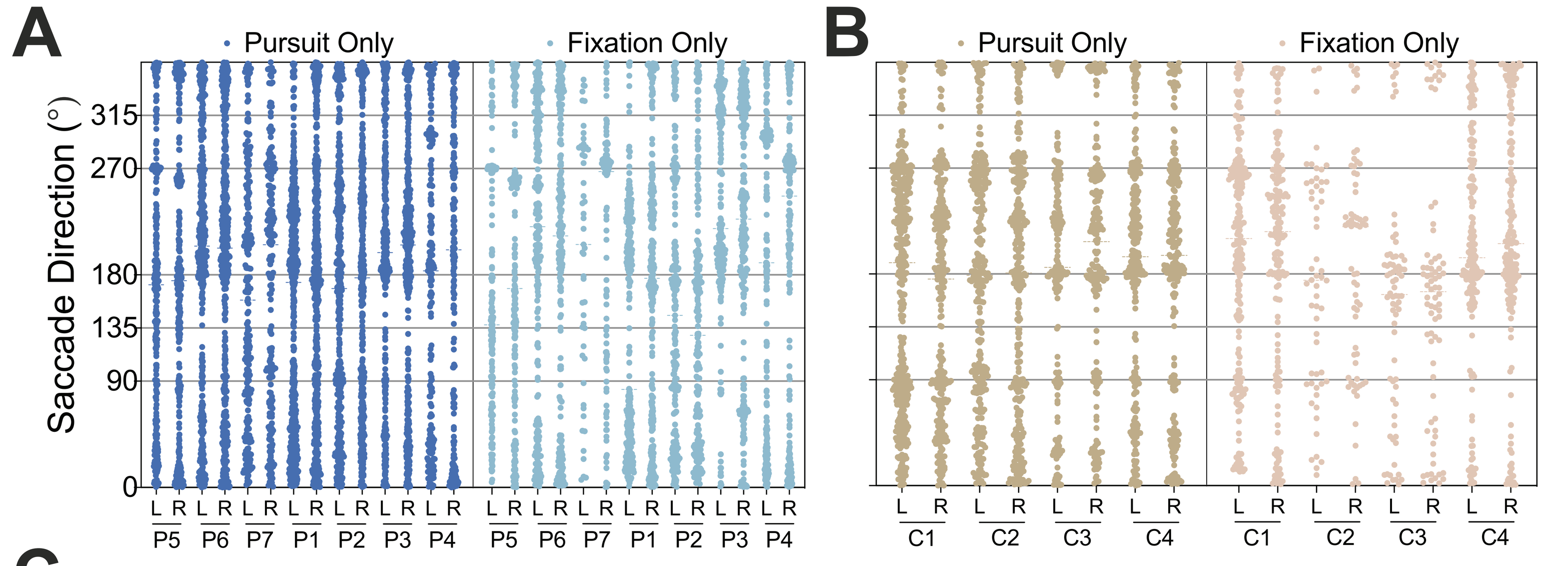
References:

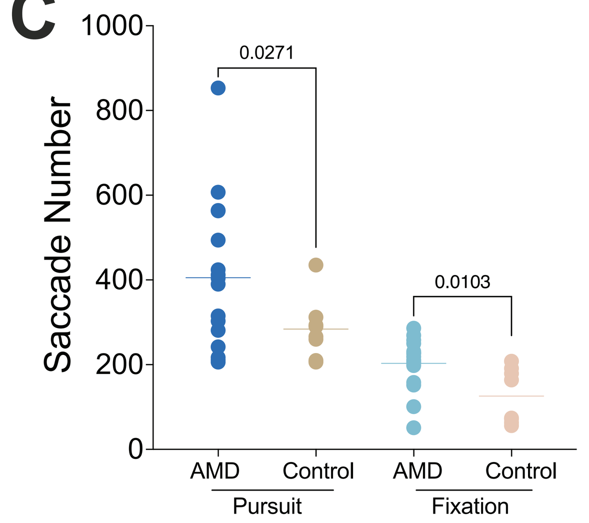
Shanidze, N., Heinen, S., & Verghese, P. (2017). Monocular and binocular smooth pursuit in central field loss. *Vision Research*, 141, 181–190.

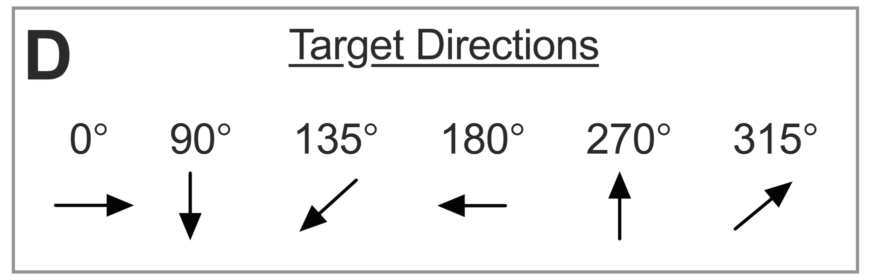
Rashbass, C. (1961). The relationship between saccadic and smooth tracking eye movements. *The Journal of Physiology*, 159, 326–338.

Shanidze, N., Fusco, G., Potapchuk, E., Heinen, S., & Verghese, P. (2016). Smooth pursuit eye movements in patients with macular degeneration. *Journal of Vision*, 16(3),

1 Participants with MD had more saccades in all directions during fixation & pursuit



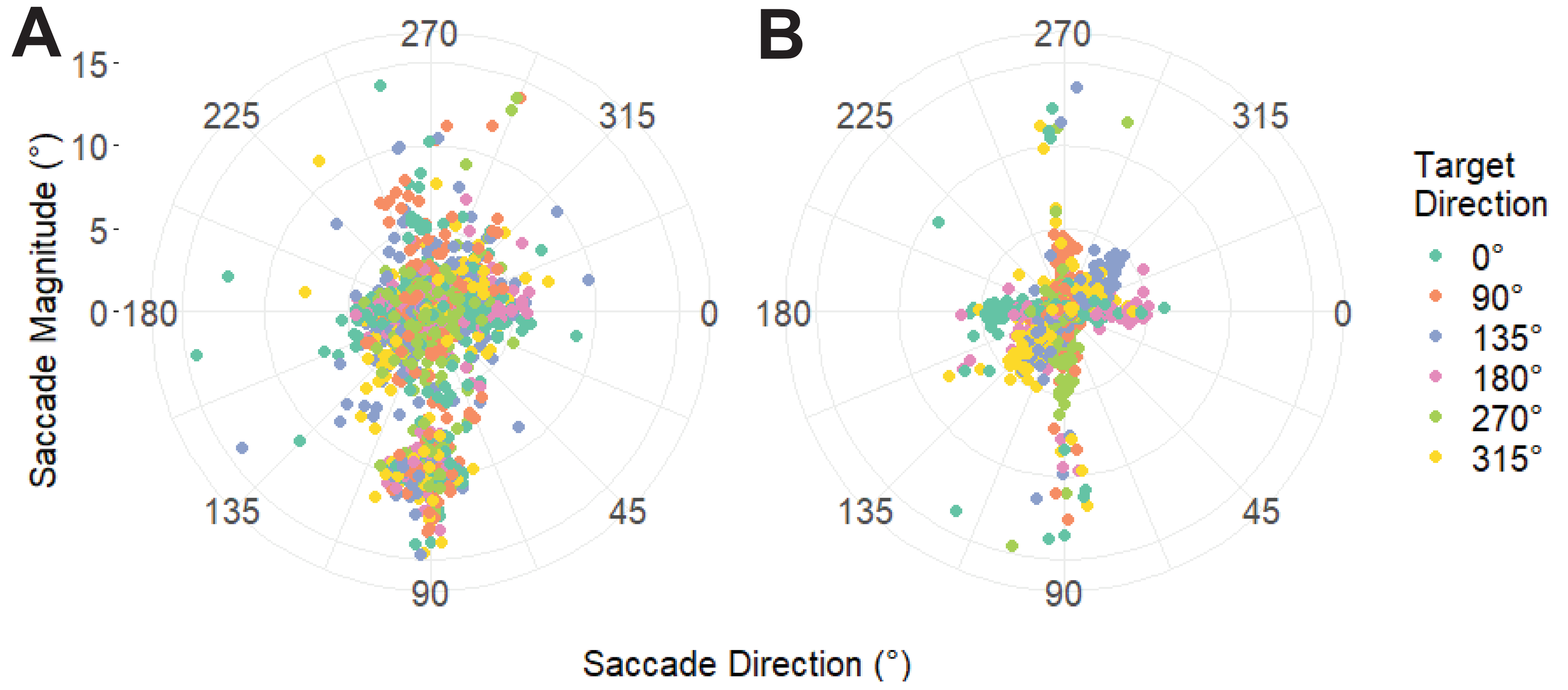




*Note: P3 has monocular MD & is excluded from further analyses that focus on the dominant/better eyes

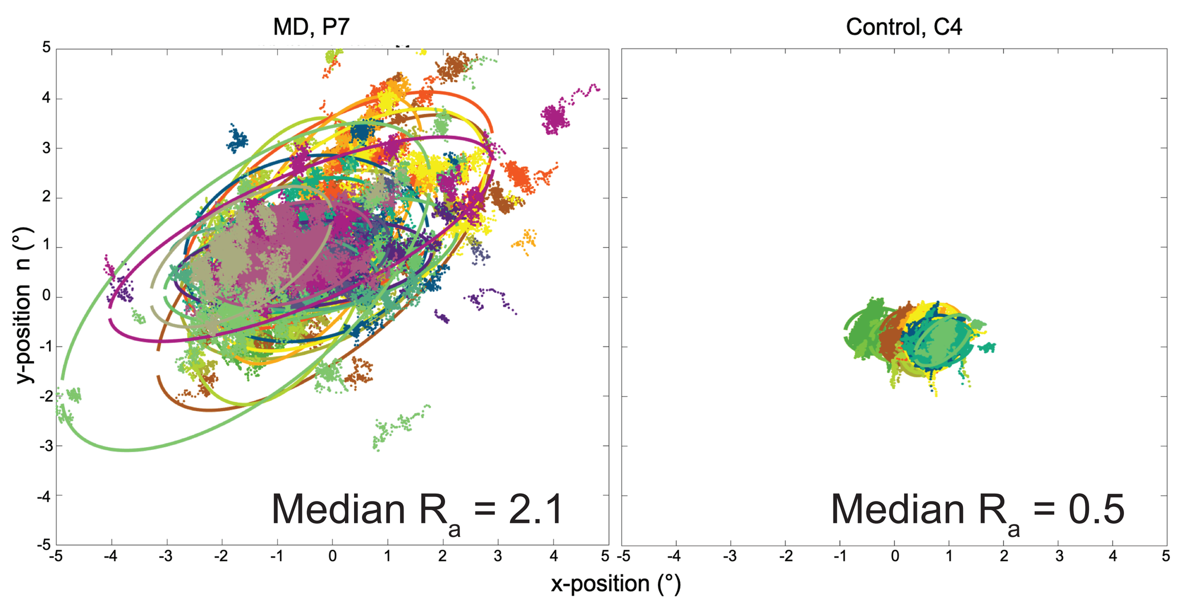
A & B: Each dot represents a single saccade made during the experiment. Each column is one eye of a single participant. MD participants (**A**) made more saccades than Controls (**B**) across all directions, including non-target directions. Overall number of saccades was significantly greater for MD participants during pursuit and fixation (**C**). Target directions are shown in **D**.

2 Unlike controls, saccades of MD participants are in non-target directions

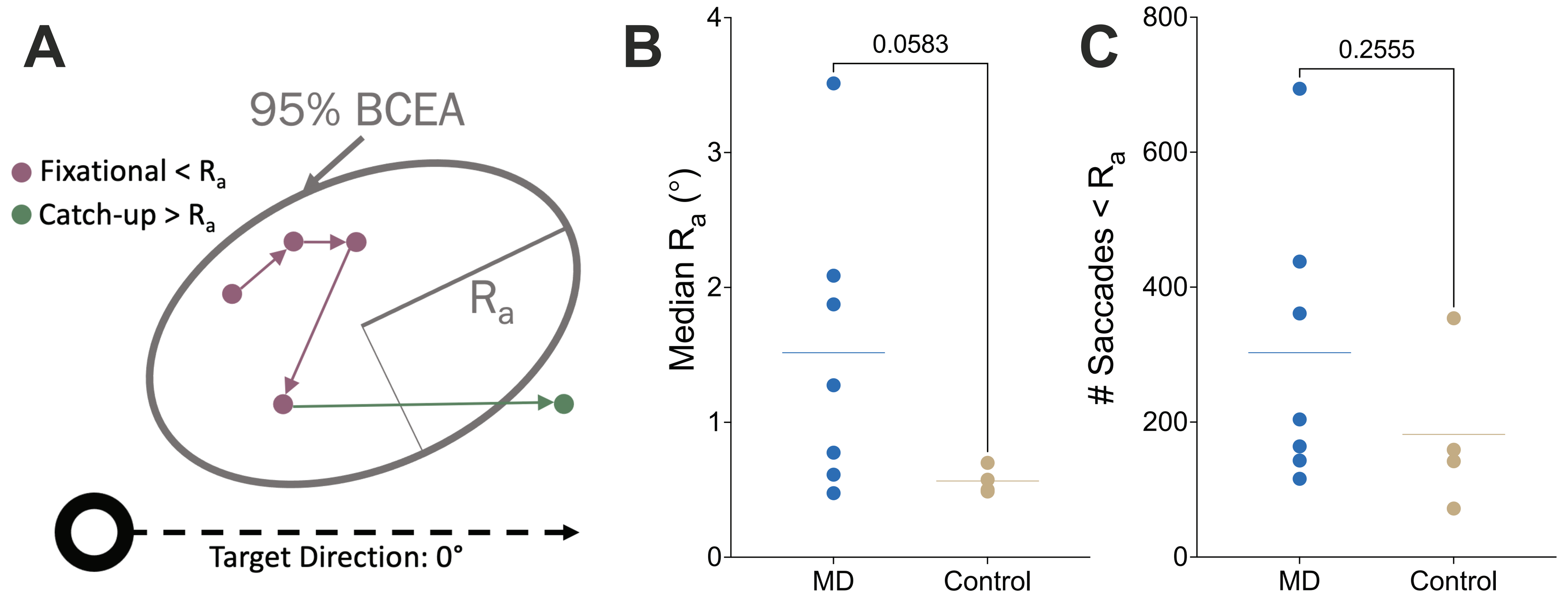


Distribution of raw saccade directions for 6 target directions (indicated by different colors) for participants with MD (**A**) and Controls (**B**). Although participants with MD had more saccades overall, their saccades were distributed more broadly, without a clear relation to target direction. Control participants' saccades tended to be along the 6 target trajectories.

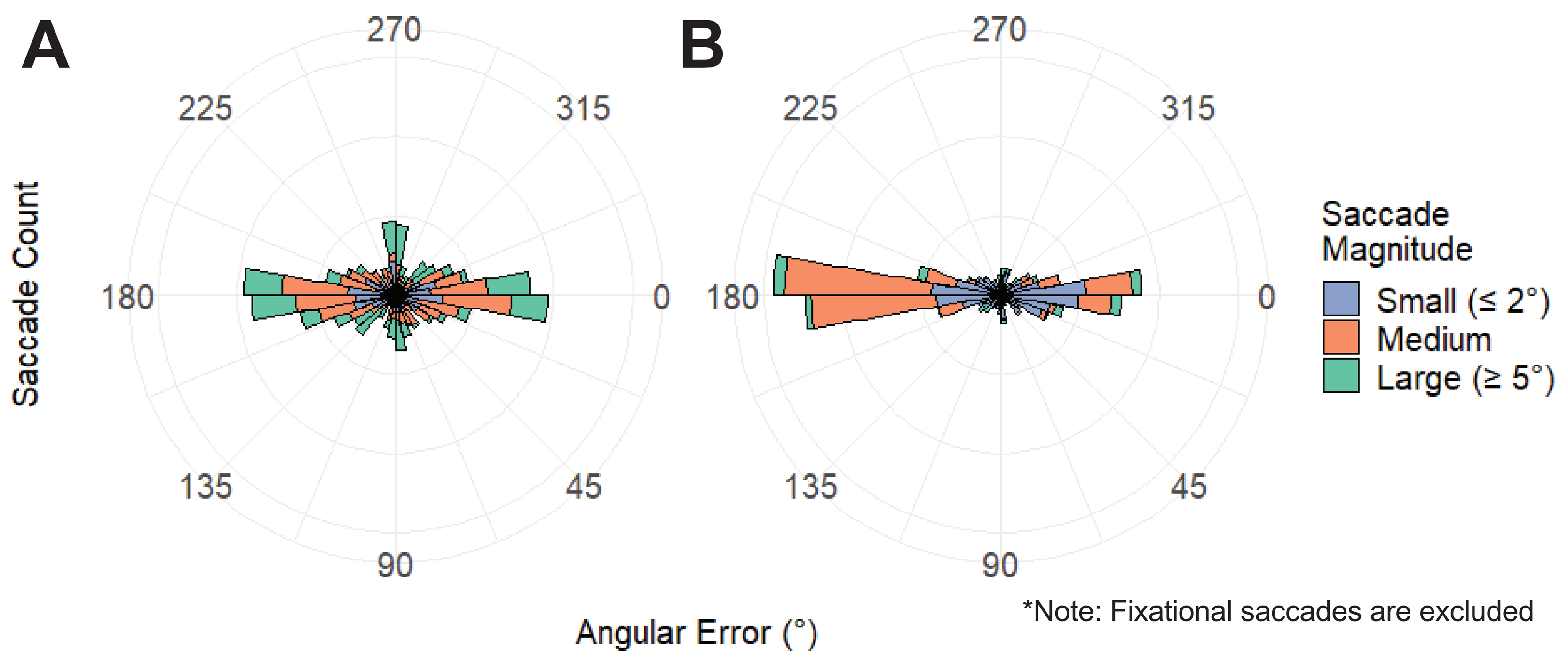
3 Does fixation instability contribute to higher saccade numbers in MD?



Left: 95% Bivariate countour ellipse areas (BCEAs) computed for a series of 10 s fixations for an MD and a control participants. Saccades smaller than the major axis (R_a) of the BCEA ellipse were defined as fixation (**A**). MD observers had greater variability in R_a (**B**). The number of saccades defined as fixational were not different between groups (**C**).

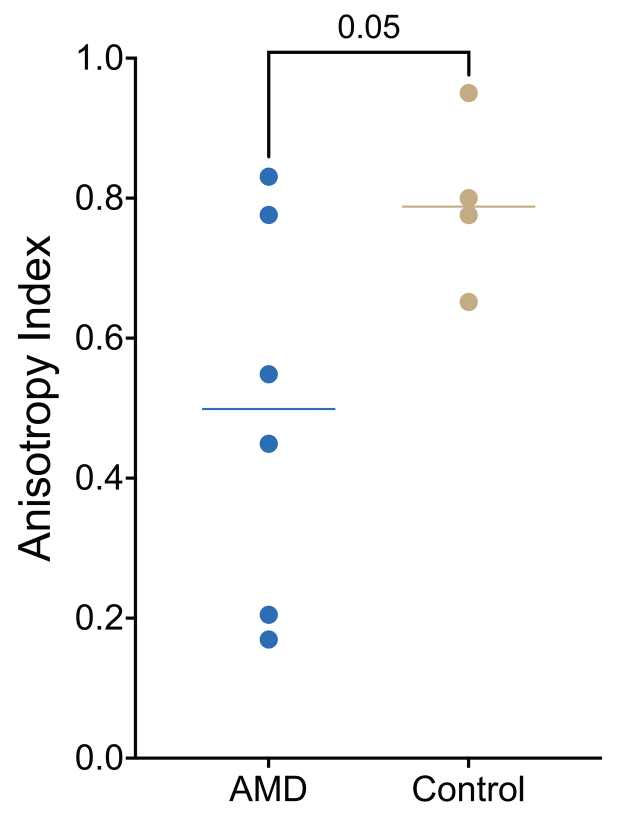


4 Unlike MDs', controls' saccades had a strong relationship to target trajectory



Histogram of saccade directions relative to target direction, stacked by saccade magnitude for MD (**A**) and Control (**B**) participants. 0° indicates saccades in the target direction. Control participants' saccades were mainly in the target direction, or in the opposite direction to catch the target at the initial step, reflected by the large magnitude of orange (medium saccade) bars in the 180° direction.

5 Saccade direction is less aligned with target direction in MD



To quantify the higher number of saccades MD participants made in non-target directions, we computed the Anisotropy Index: a comparison of saccades aligned with and orthogonal to the target (1 = perfect alignment).We found controls had a marginally higher anisotropy index than MDs, indicating better alignment with target direction (two-way t-test, Welch correction for unequal SD).

MD Mean AI: 0.4965
Control Mean AI: 0.7945

$$\text{Anisotropy Index} = \frac{\#\parallel - \#\perp}{\#\parallel + \#\perp}$$

Summary

- Participants with MD made significantly more saccades during fixation and pursuit than age-matched controls (Figure 1C).
- Saccades of MD participants during pursuit occurred in a broad range of directions relative to target direction (Figure 2).
- MD participants had more variable fixational stability, with some participants making larger fixational saccades (Figure 3B). The number of saccades during fixation were not significantly different across groups (Figure 3C).
- Even after excluding fixational saccades, saccade directions during pursuit were not as closely linked to target direction in MDs as in control participants.
- MD participants' saccades were mariginally less aligned with the target direction than controls' (Figure 5).

Conclusions

Despite higher frequency, a large number of saccades during pursuit in MD participants are not in the target direction, and thus are not catch-up saccades that serve to keep the eye on the target. The saccades in non-target directions cannot be fully accounted for by the significant increase in saccades during fixation. Thus, MD participants do not effectively use saccades to compensate for the lower pursuit gains reported previously (Shanidze et al., 2017; Shanidze et al., 2016).

Acknowledgements:

This work was supported by NIH R01 grants EY022394 & EY027390 to PV and F32 grant EY025151 & K99-R00 grant EY026994 to NS.