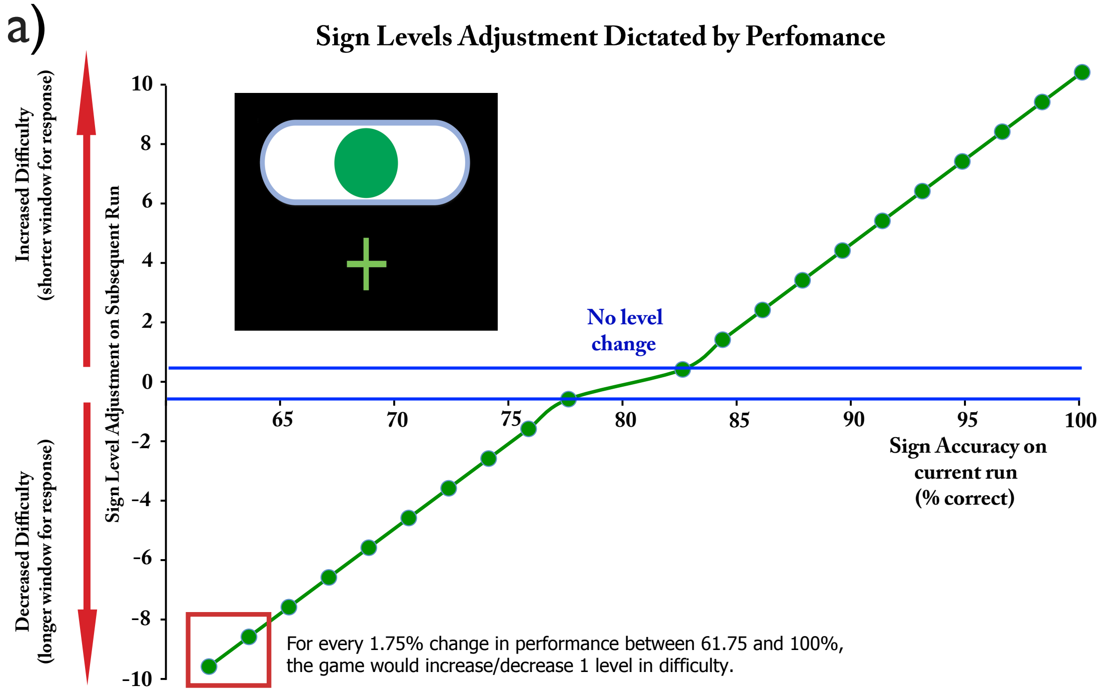
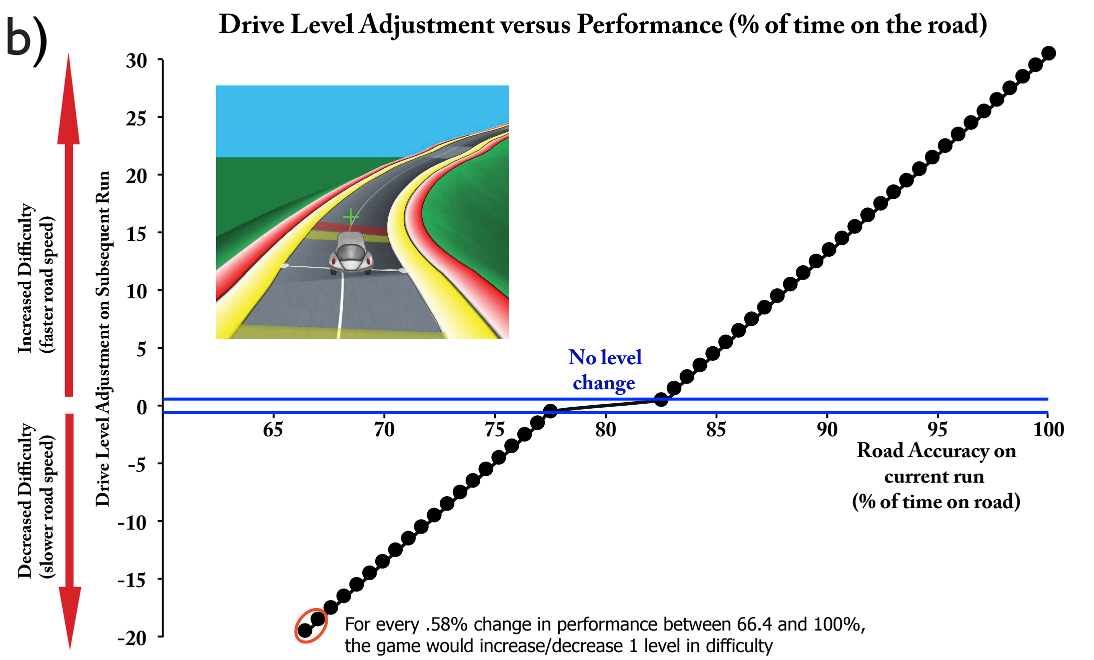
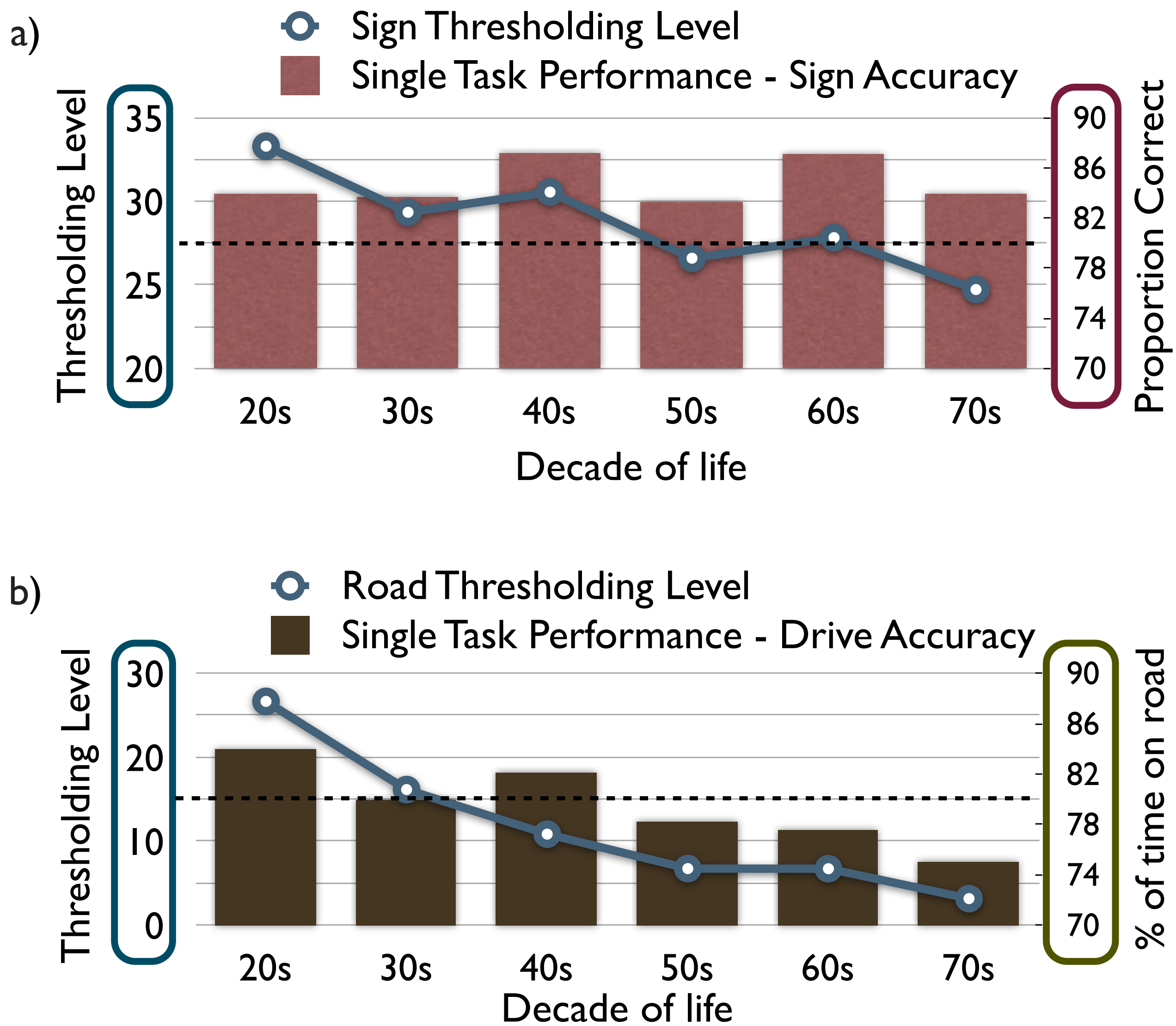
a)



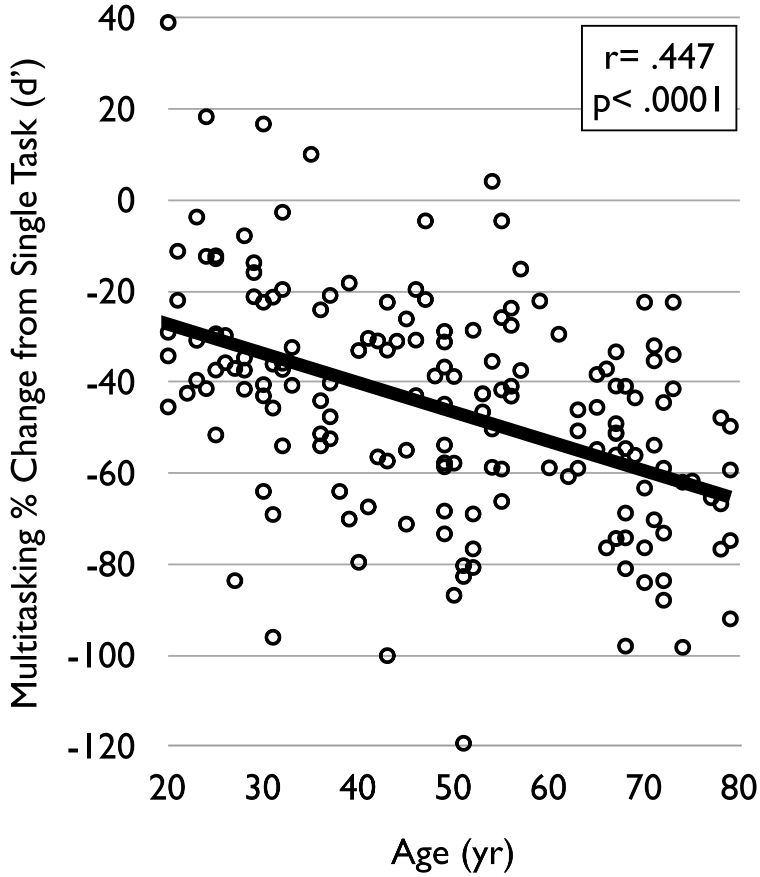
b)



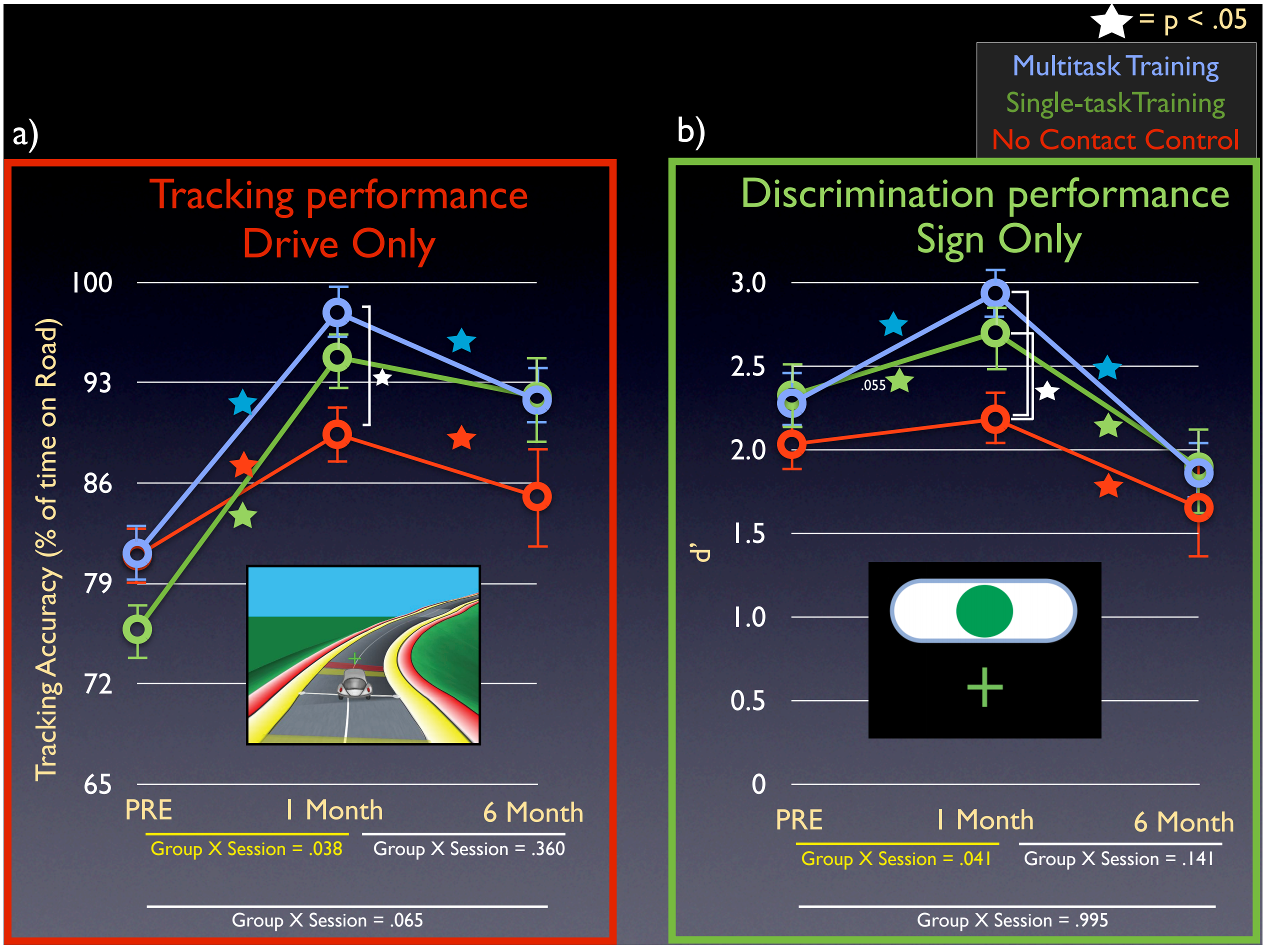
<u>Supplementary Figure 1.</u> Sign and Road level adjustments for thresholding and training. a, Sign level selection based on performance of the most recently completed run: for example, a participant who performed at 90% accuracy on a given Sign run had a 4 level increase in difficulty (thus, a shorter time window to respond) on their subsequent run. Note that the algorithm was designed to have performance equilibrate around ~80% (thus no level change), as visualized by a temporary flattening of the displayed vector between 77.5-82.5% that falls between the solid blue lines. b, Road level selection based on performance of the most recently completed run.



<u>Supplementary Figure 2.</u> Thresholding Level and Single task performance for Experiment 1. a, A sign level of 29 represents an 500msec response window to targets signs, with each increase/decrease in level corresponding with a 10msec change in this response window (e.g. a level of 30 = 490msec window, a level of 28 = 510msec window (see **Thresholding** section for more details). Sign Level showed a main effect of age ($F(5,173)= 6.64$, $p< .0001$), unlike single task "Sign Only" performance ($F(5,173)= 1.97$, $p= .09$. b, A road level of 0 indicates a very slow visuomotor tracking experience with each increase in level being associated with the road coming by a faster pace (see http://www.youtube.com/watch?v=qnW9iMTSD0E to visualize road levels of 0 and 40). Road level ($F(5,173)= 22.27$, $p< .0001$) and tracking accuracy ($F(5,173)= 2.27$, $p= .05$) both showed a main effect of decade.

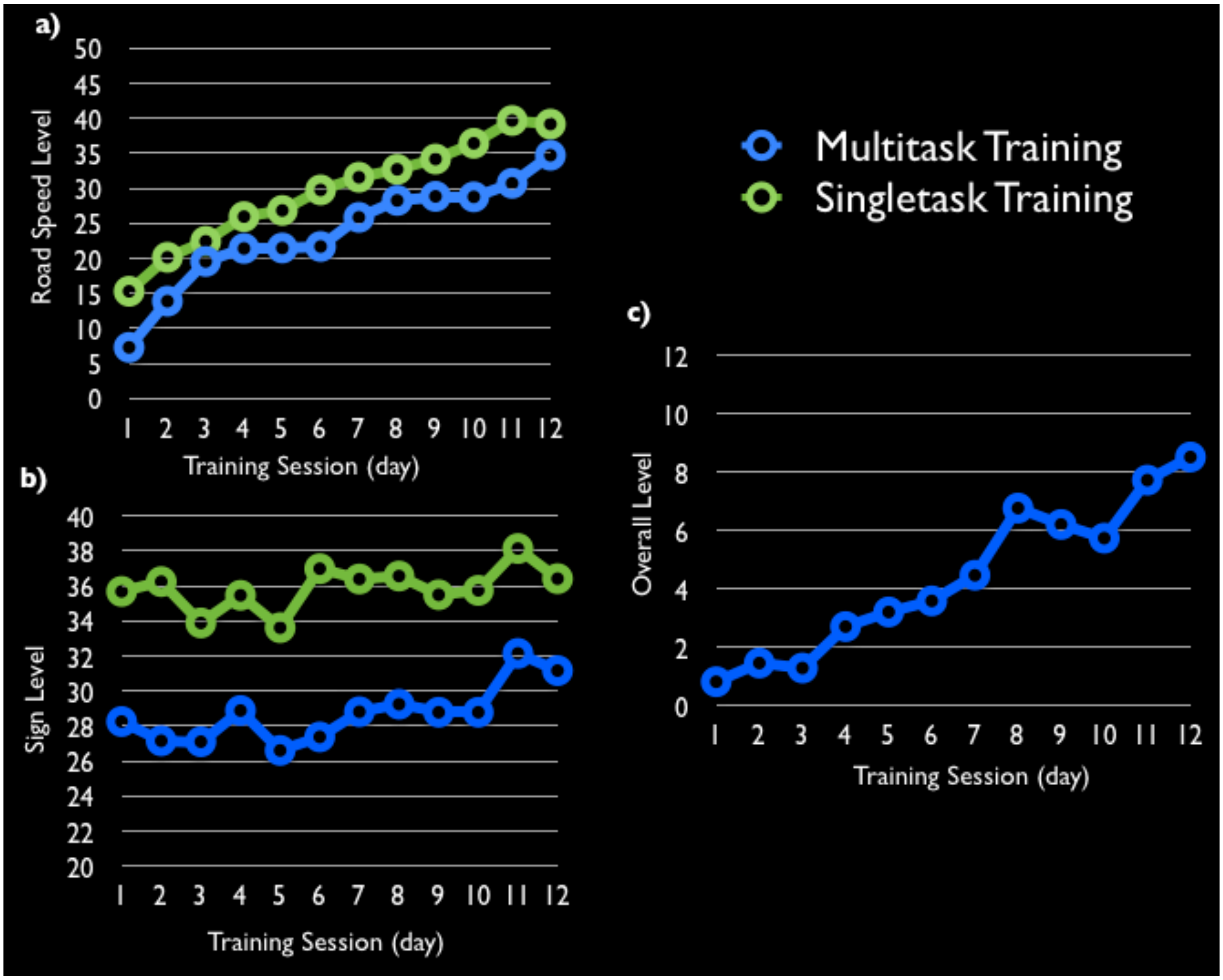


<u>Supplementary Figure 3</u>. Correlation between age and multitasking cost across the lifespan.

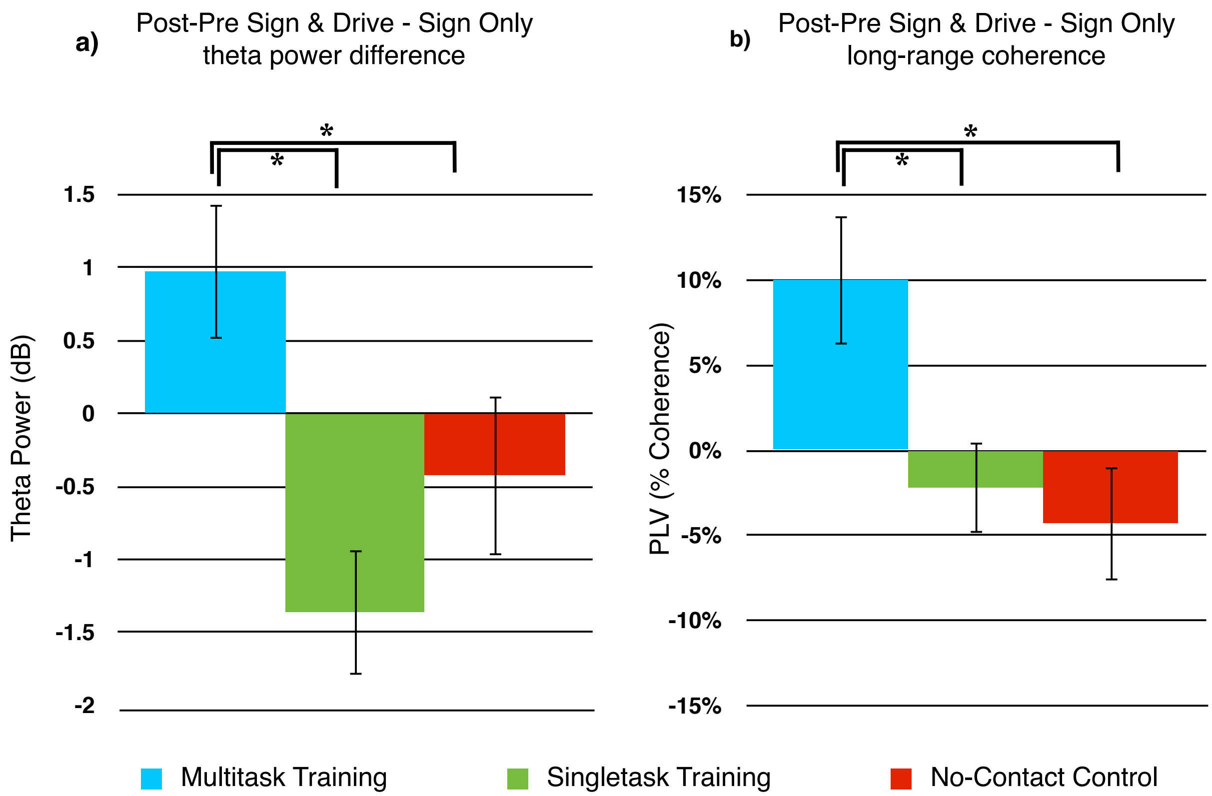


Supplementary Figure 4. Tracking ('Drive Only') and Discrimination ('Sign Only') performance for Experiment 2. a, Tracking performance showed a main effect of session ($F(2,72)= 33.95$, $p< .0001$) but neither an effect of group ($p> .25$) nor a group X session interaction ($p> .08$). ANOVAs testing for group differences at each time point revealed only a difference at the 1-month (Post-training) mark ($F(2, 45)= 5.06$, $p= .011$), with MTT showing better performance than the NCC group ($p< .05$). An improvement from Pre- to Post-training was present for all groups (each paired t-test $p< .05$), as well as a decrease in performance for the MTT and NCC groups at the 6 month mark ($p< .05$).

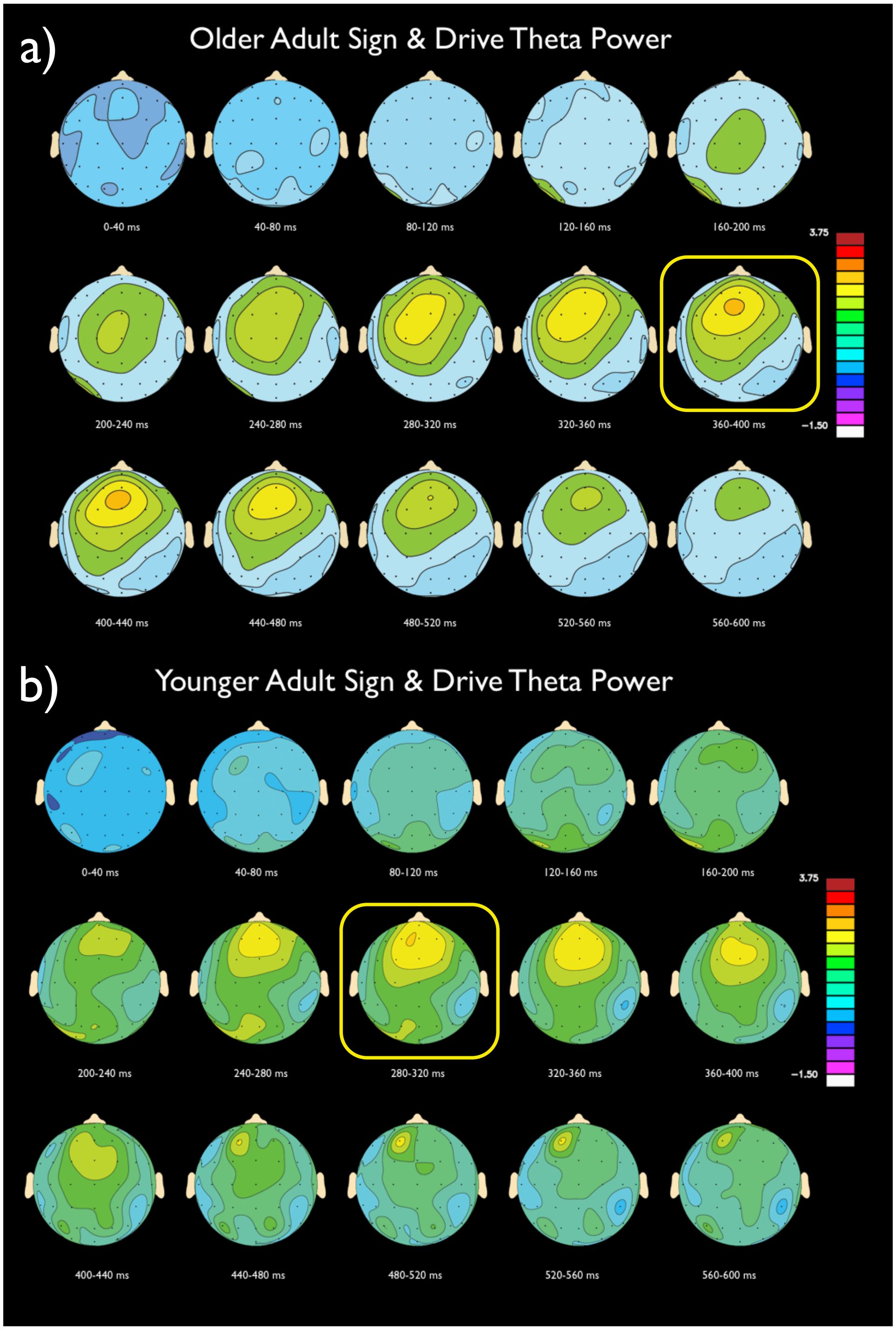
b, Discrimination performance condition showed a main effect of session ($F(2,72)= 23.66$, $p< .0001$) but neither an effect of group ($p> .12$) nor a group X session interaction ($p> .18$). ANOVAs testing for group differences at each time point revealed only a difference at the 1 month (Post-training) mark ($F(2, 45)= 5.64$ $p= .007$), with both MTT and STT showing better performance than the NCC group ($p< .05$). A group X condition interaction illustrated the differential improvement from Pre- to Post-training for the MTT and STT groups ($F(2, 43)= 3.45$, $p= .041$), while all groups showed a significant decrease in performance at the 6 month mark (paired t-tests: $p< .05$).



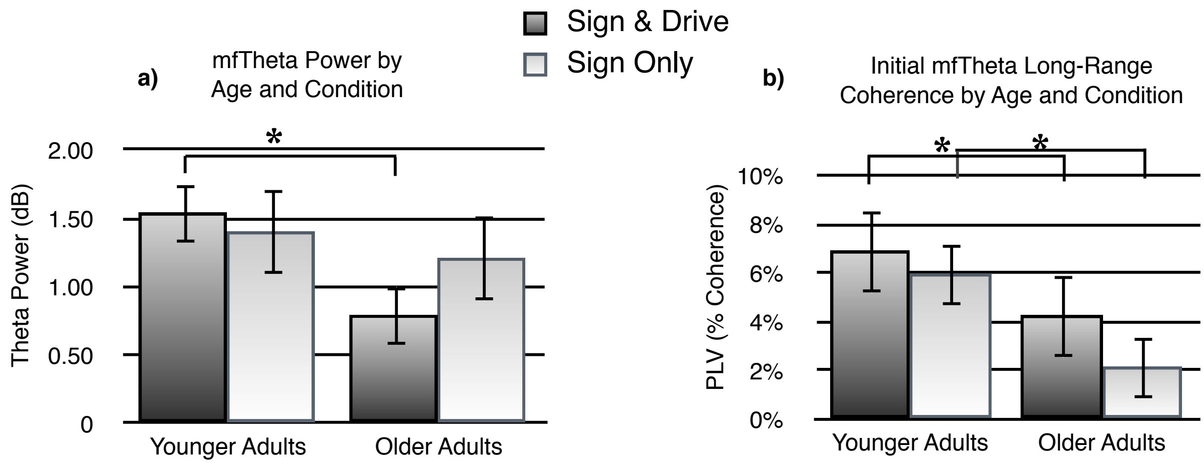
Supplementary Figure 5. Group road, sign, and overall levels. a, Group mean road level score across each day of training. A main effect of session was present ($F(11, 264)= 33.24$, $p< .0001$), but neither an effect of group ($p> .80$) nor a group X session interaction ($F(11, 264)= 1.05$, $p> .40$) was observed. b, Group mean sign level score across each day of training. A main effect of session ($F(11, 264)= 4.26$, $p= .002$) and group ($F(1, 30)= 10.47$, $p= .003$), but no group X session interaction was observed ($F(11, 264)= .96$, $p> .45$). c, Multitasking training group mean overall level score (the reward mechanism that accrued for each run where performance on each constituent task was above 80% led to the 1 ‘Overall’ level increase) across each day of training, which showed a main effect of training session ($F(11, 165)= 3.20$, $p= .022$).



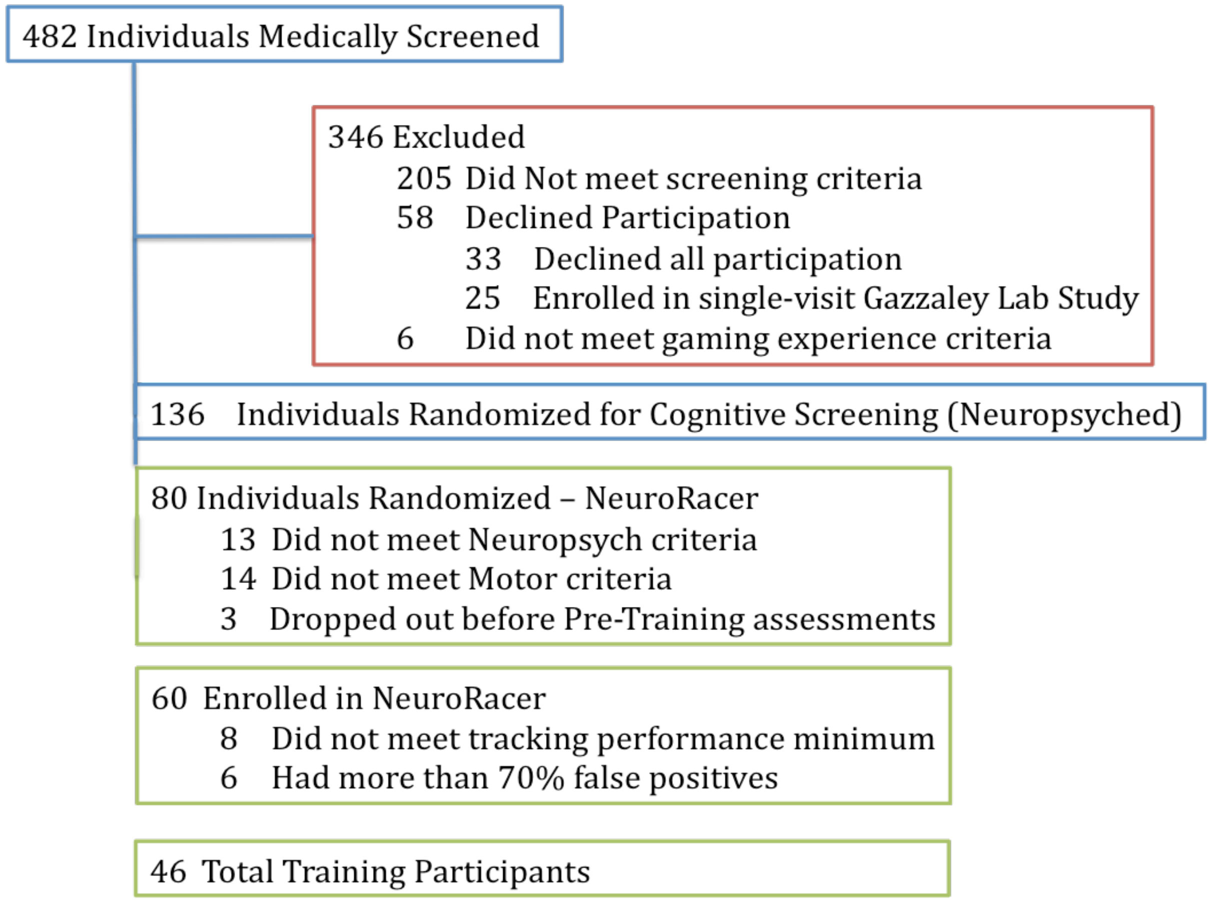
<u>Supplementary Figure 6</u>. Post-Pre "Sign and Drive" – "Sign Only" neural activity. For each neural measure, a group X condition X session interaction was present (F(2,41)> 4.98, p< .01, d> .93 for each comparison). a, Midline frontal theta power, d for MTT vs ACC = 1.35; MTT vs. NCC = 1.00. b, Long-range theta coherence, d for MTT vs ACC = .53; MTT vs. NCC = .70 *= p< .05 between groups. Bars represent standard error.



Supplementary Figure 7. Topographic maps of ERSP activity from stimulus (sign) onset in 40msec increments. a, All older adults collapsed across group and session for the "Sign and Drive" condition, with the window of interest used for statistical analyses in Experiment 2 & 3 highlighted in yellow. b, All younger adults for the "Sign and Drive" condition, with the window of interest used for statistical analyses in Experiment 3 highlighted in yellow.

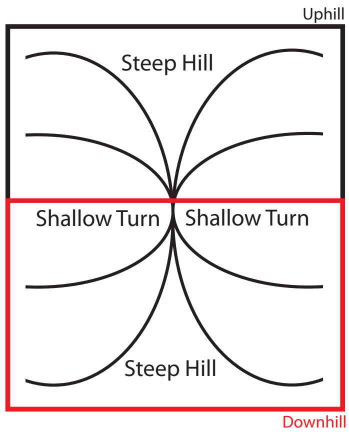


Supplementary Figure 8. Younger vs. Older adult neural activity by condition. For each neural measure, a group x condition interaction was not significant ($F(1,61) < 1.48$, $p > .20$ for each comparison), while a main effect of group was significant ($p < .05$ for each measure). a, Midline frontal theta power. b, Long-range theta coherence. *= $p < .05$ between groups. Bars represent standard error.

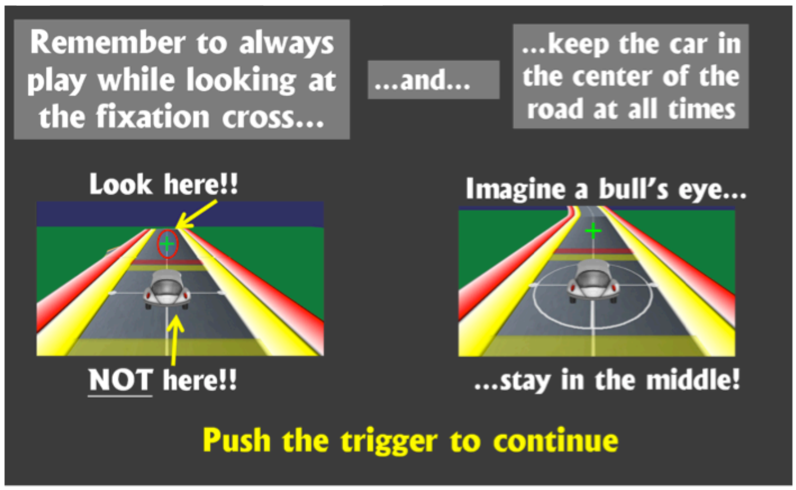


Supplementary Figure 9. Experiment 2 recruitment schematic.

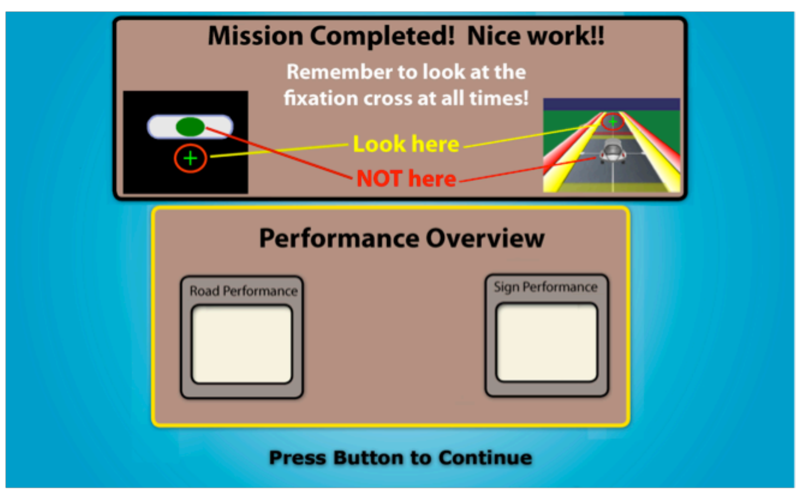
a)



b)



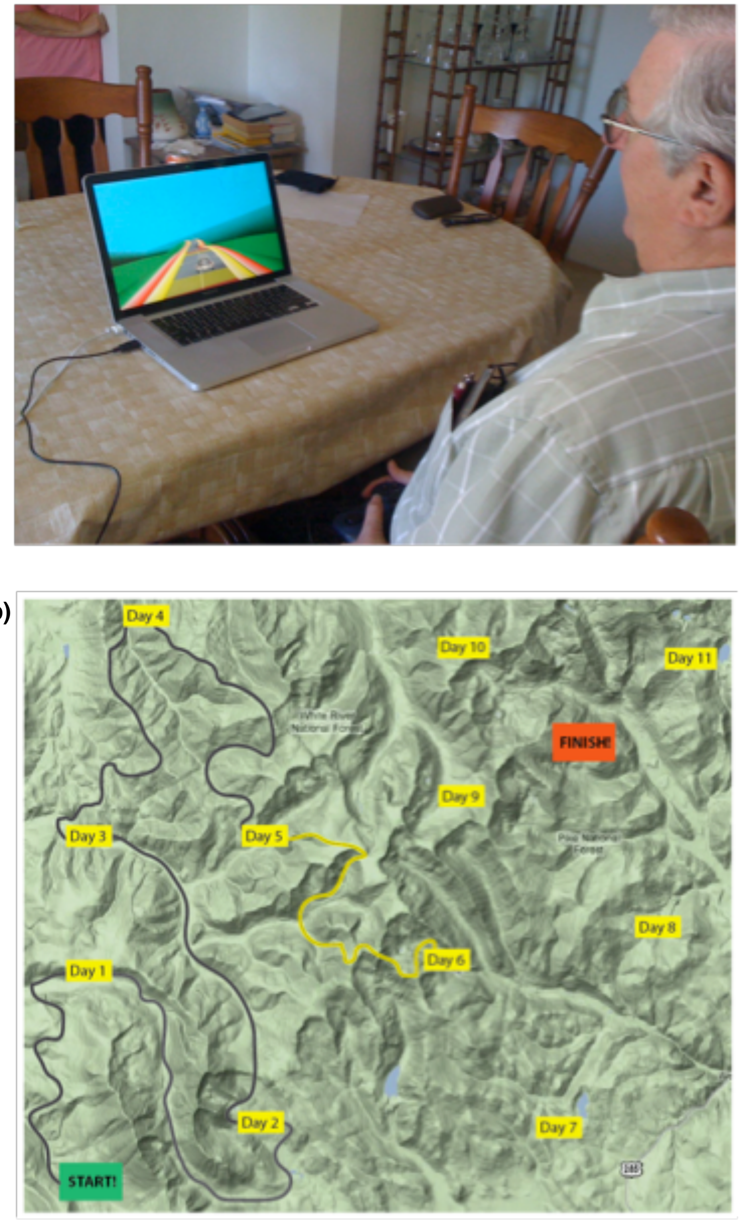
c)



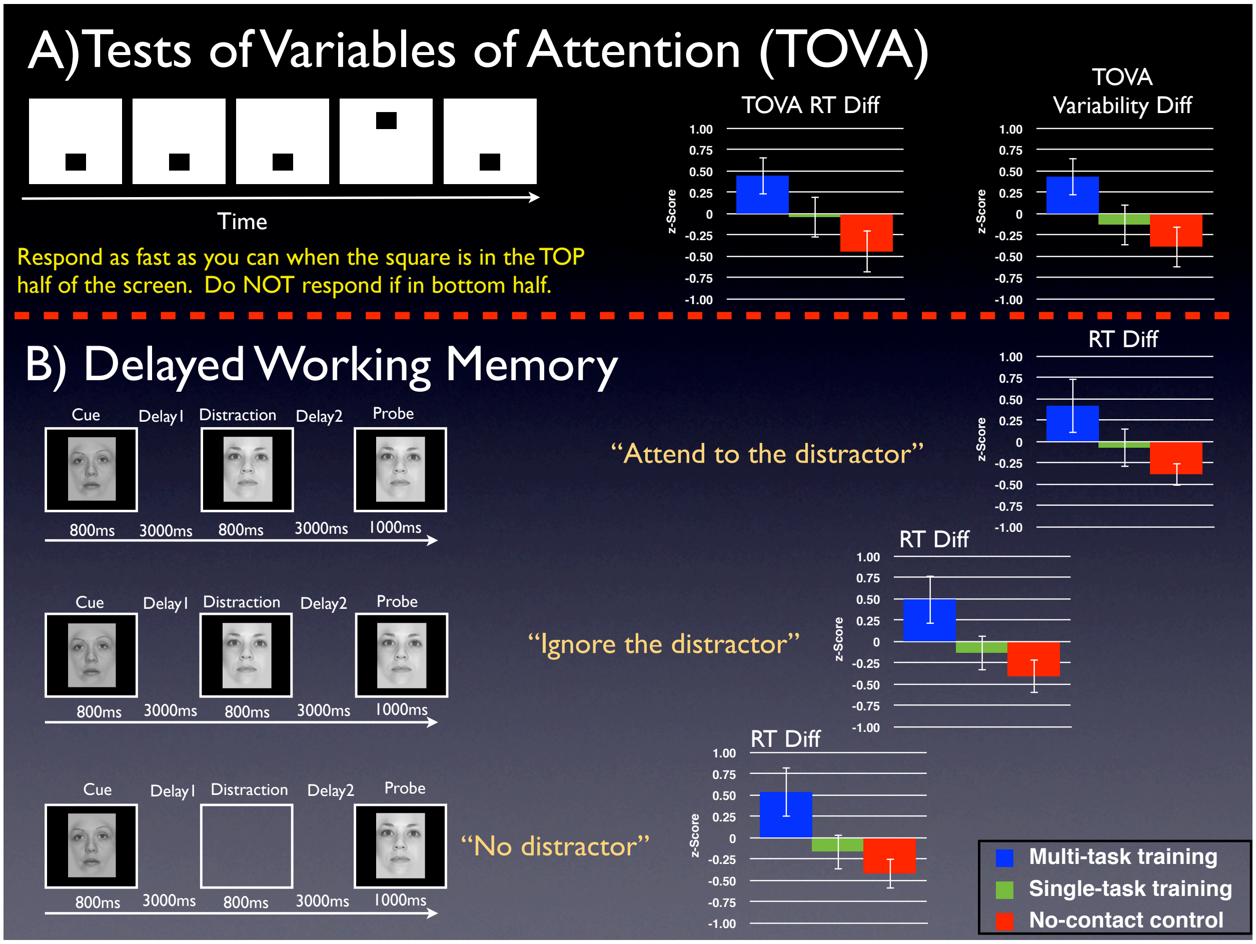
Supplementary Figure 10. a, Schematic of possible road pieces for NeuroRacer, with hills and turns during the game each having a function of steepness in each direction. b, In-game reminder illustrating how participants were reminded to keep their focus at the fixation cross and how to drive most accurately. c, Example of feedback screen given at the end of each experimental run.

a)

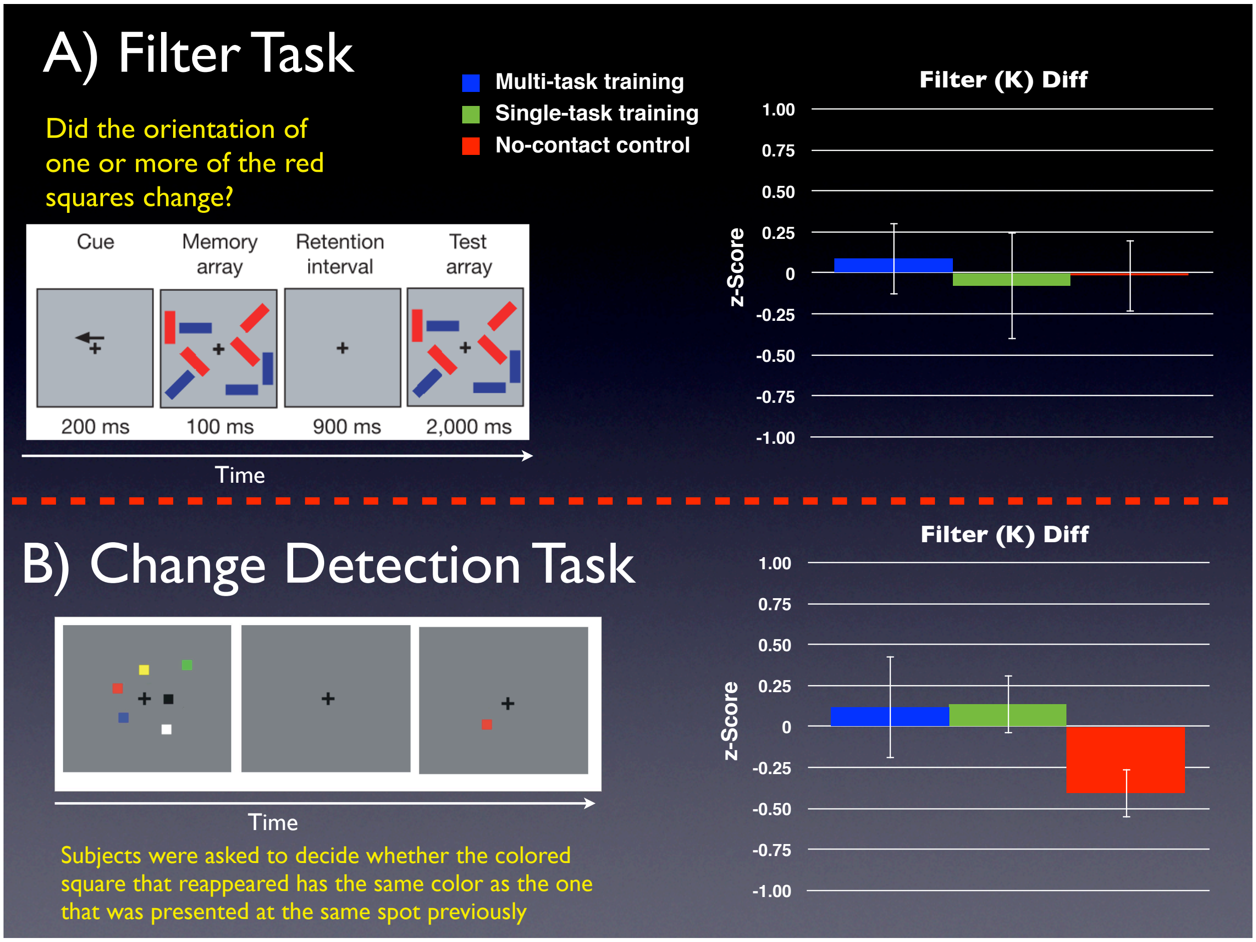
b)



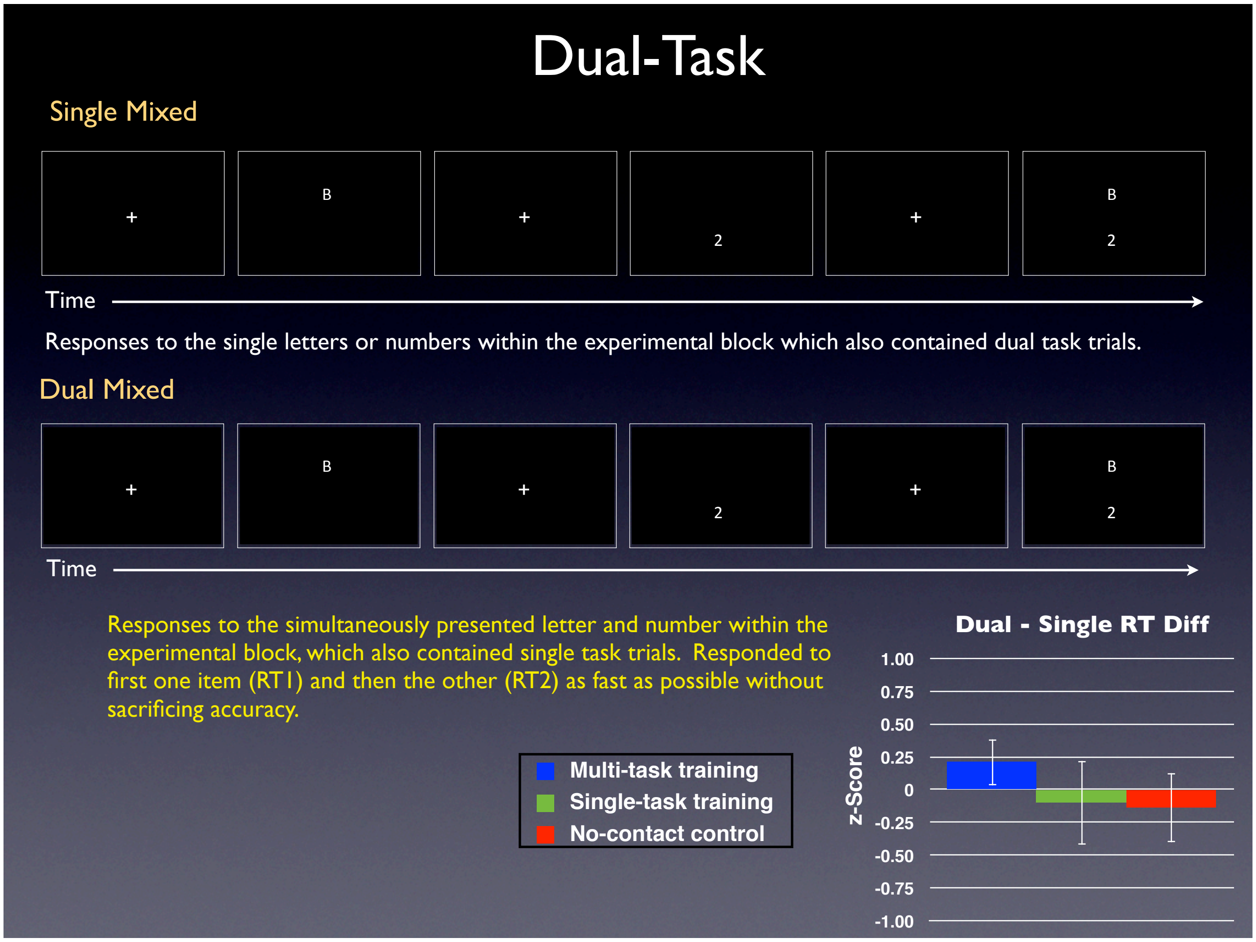
<u>Supplementary Figure 11</u>. Images of training experience. a, Example of one participant training on the NeuroRacer platform at home. b, Fictional map shown to participants each day of training representing the ‘journey’ they have taken thus far on their training.



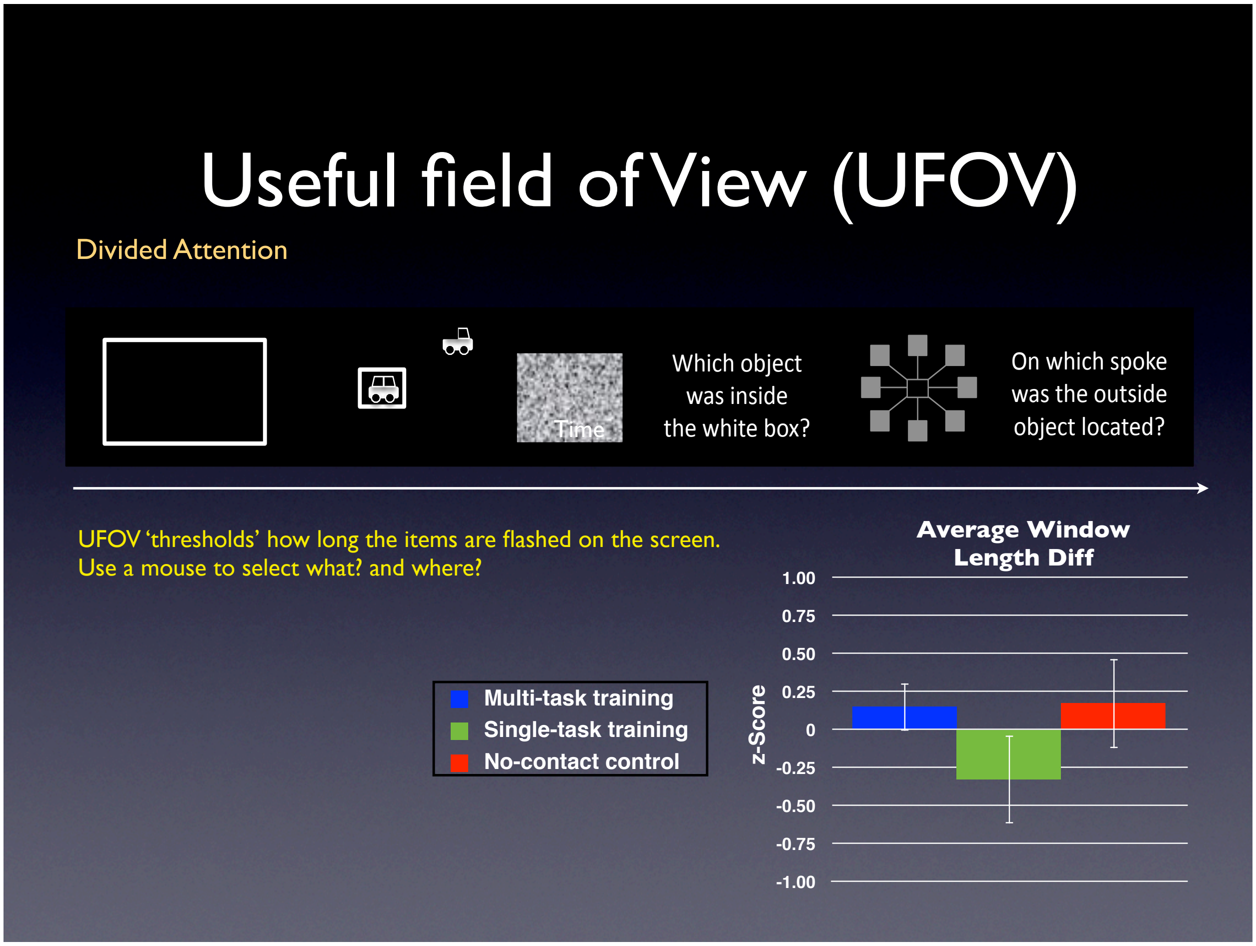
Supplementary Figure 12. Illustration of TOVA and delayed working memory task with Post-Pre difference scores for each group (z-scored for facilitating between-test comparisons; Statistics in Supplementary Table 2). a, Tests of Variables of Attention (TOVA) task[1]. b, Delayed working memory task, with each of the three different conditions[2,3].



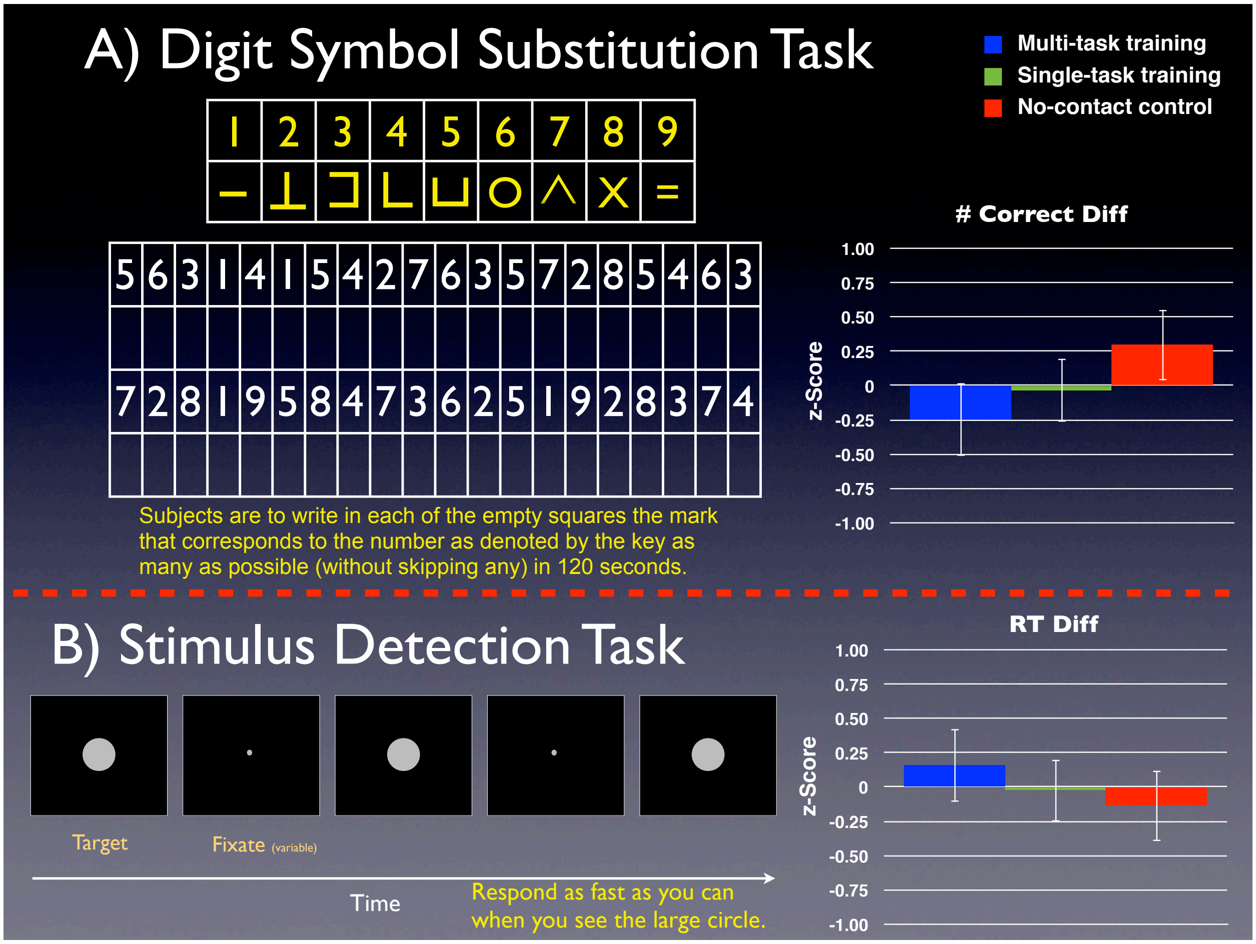
<u>Supplementary Figure 13</u>. Filter task[4] and change detection task[5] with Post-Pre difference scores for each group (z-scored for facilitating between-test comparisons; Statistics in Supplementary Table 2). a, Filter task shown with set size of 4 items. b, Change detection task.



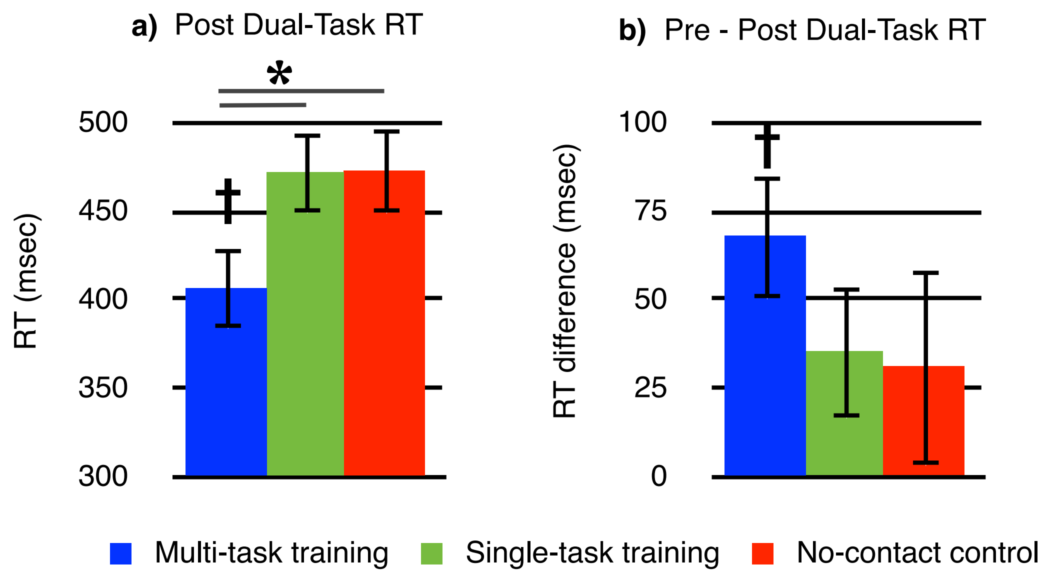
<u>Supplementary Figure 14</u>. Illustration of dual-task paradigm[6] with Post-Pre difference scores for each group (z-scored for facilitating between-test comparisons; Statistics in Supplementary Table 2). Performance calculated through the dual mixed condition by RT2-RT1. This measure is described as a *task-difference effect* that reflects the engagement of updating/monitoring abilities by contrasting the completion of each component task[7].



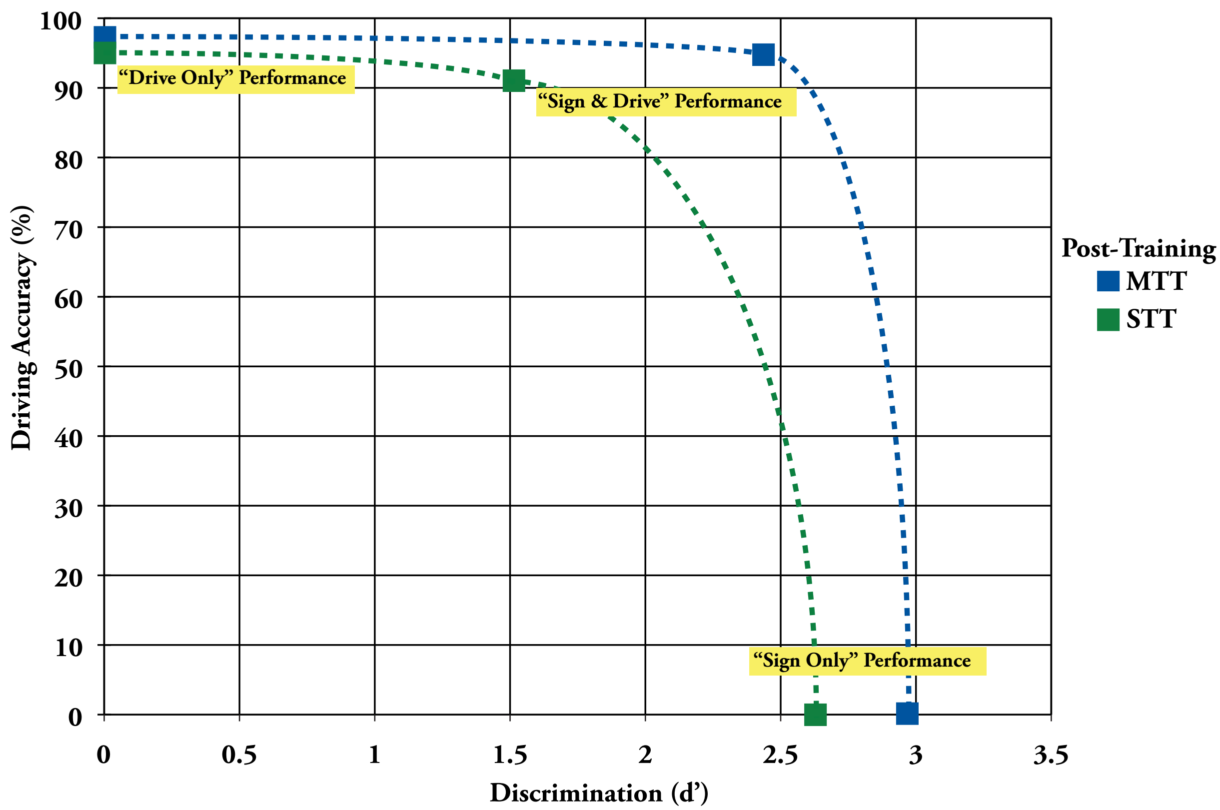
Supplementary Figure 15. Useful field of view (UFOV)[8] with Post-Pre difference scores for each group (z-scored for facilitating between-test comparisons; Statistics in Supplementary Table 2).



<u>Supplementary Figure 16</u>. Cognitive transfer control tasks with Post-Pre difference scores for each group (z-scored for facilitating between-test comparisons; Statistics in Supplementary Table 2). a, Digit symbol substitution task. b, Stimulus detection task.



<u>Supplementary Figure 17</u>. Dual-task performance assessed with ANCOVA and ANOVA (RT on 2nd task – RT on 1st task). a, ANCOVA showing post-training performance for each group (using pre-training performance as a covariate). b, ANOVA (pre-post RT difference score) performance for each group. †= p< .05 within group improvement from Pre to Post, *= p< .05 between groups. Error bars represent standard error.



Supplementary Figure 18. Single and dual-task performance Post-training assessed with AOC curves for the MTT and STT groups. "Drive Only", "Sign Only", and "Sign & Drive" performance on each respective measure (d' and driving accuracy) are plotted for each group. If MTT participants truly learned to multitask better, rather than adopting a tradeoff strategy, then the MTT AOC curve should lie "north-east" relative to the curve for STT participants, which is exactly what was observed.

Supplementary Table 1a. Group d' by condition. Mean (St.Error)

	d' S&D	**d' SO**	**d' 1month S&D**	**d' 1month SO**	**d' 6month S&D**	**d' 6month SO**
Experiment 1						
Twenty-year-olds	1.77 (.09)	2.49 (.11)	-	-	-	-
Thirty-year-olds	1.66 (.14)	2.76 (.13)	-	-	-	-
Forty-year-olds	1.54 (.12)	2.82 (.09)	-	-	-	-
Fifty-year-olds	1.34 (.13)	2.48 (.13)	-	-	-	-
Sixty-year-olds	1.33 (.10)	2.90 (.09)	-	-	-	-
Seventy-year-olds	1.02 (.14)	2.62 (.09)	-	-	-	-
Experiment 2						
Multitask Training	.77 (.22)	2.27 (.12)	2.42 (.16)	2.93 (.15)	1.44 (.20)	1.86 (.17)
Singletask Training	.97 (.20)	2.32 (.16)	1.52 (.29)	2.69 (.18)	.70 (.28)	1.95 (.22)
No-Contact Control	.64 (.15)	2.03 (.14)	.83 (.21)	2.18 (.15)	.34 (.19)	1.65 (.17)
Experiment 3						
Younger adults	1.74 (.12)	2.75 (.13)	-	-	-	-
Older adults	.79 (.11)	2.2 (.08)	-	-	-	-

Supplementary Table 1b. Group RT by condition. Mean (St.Error)

	RT S&D	RT SO	RT 1month S&D	RT 1month SO	RT 6month S&D	RT 6month SO
Experiment 1						
Twenty-year-olds	444 (7)	394 (5)	-	-	-	-
Thirty-year-olds	476 (21)	409 (16)	-	-	-	-
Forty-year-olds	494 (13)	421 (8)	-	-	-	-
Fifty-year-olds	548 (26)	466 (14)	-	-	-	-
Sixty-year-olds	552 (14)	451 (9)	-	-	-	-
Seventy-year-olds	601 (19)	484 (15)	-	-	-	-
Experiment 2						
Multitask Training	616 (43)	430 (12)	482 (31)	395 (9)	480 (11)	436 (10)
Singletask Training	560 (30)	436 (11)	599 (90)	411 (15)	559 (35)	449 (18)
No-Contact Control	567 (22)	458 (10)	604 (46)	446 (15)	556 (21	455 (15)
Experiment 3						
Younger adults	455 (13)	393 (10)	-	-	-	-
Older adults	579 (20)	444 (10)	-	-	-	-

S&D: "Sign & Drive", SO: "Sign Only"

<u>Supplementary Table 2.</u> Cognitive tests (p-values and effect sizes).

<u>Cognitive Control Tasks</u>	**Session X Group**	**ANCOVA**	**Session main effect**	**Post-Pre MTT > STT? (Cohen's d)**	**Post-Pre MTT > NCC? (Cohen's d)**
TOVA – RT[1]	**p= .04**	**p= .03**	**p= .03**	No (.46)	**YES (.89)**
TOVA – RT Variability[1]	p= .08	**p= .05**	**p= .03**	**YES (.54)**	**YES (.75)**
Delayed-recognition working memory task ignoring distraction (RT)[2,3]	**p= .03**	p= .09	p= .90	**YES (.61)**	**YES (.90)**
Delayed-recognition working memory task attend to distraction (RT)[2,3]	p= .08	p= .14	p= .18	No (.42)	**YES (.78)**
Delayed-recognition working memory task no distraction (RT)[2,3]	**p= .02**	**p= .05**	p= .97	**YES (.67)**	**YES (.98)**
Dual-task paradigm (RT difference)[6]	p= .58	p= .09	**p= .01**	No (.27)	No (.35)
Useful field of view (avg. window length)[8]	p= .17	p= .08	p= .61	No (.68)	No (.02)
Filter task* (4 distracters; Capacity (k))[4]	p= .90	p= .65	p= .56	No (.15)	No (.11)
Change detection task* (set size = 4; Capacity (k))[5]	p= .20	p= .11	p= .52	No (.05)	No (.54)
<u>Controls</u>					
Stimulus Detection task (RT)	p= .73	p= .94	**p= .02**	No (.14)	No (.32)
Digit Symbol (total correct)[9]	p= .32	p= .33	p= .09	No (.22)	No (.51)

- ** Performance at set size of 4 / # of distracters of 4 shown, with similar results observed (not reported) at 0, 2, and 6, respectively.
- **Yes**: p< .05, No: p> .05).

<u>Supplementary Table 3.</u> Participant age and gender by experiment.

	N	Mean age (STDEV)	# of males	Years of education (STDEV)
<u>Experiment 1</u>	(174)			
Twenty-year-olds	31	24.5 (3.0)	15	
Thirty-year-olds	29	33.4 (2.9)	15	
Forty-year-olds	28	45.6 (3.1)	14	
Fifty-year-olds	29	53.7 (2.4)	15	
Sixty-year-olds	27	65.9 (2.5)	12	
Seventy-year-olds	29	73.3 (3.8)	16	
<u>Experiment 2</u>	(46)			
Multitask Training	16	64.9 (5.2)	5	16 (1.3)
Singletask Training	15	68.8 (6.8)	6	17.6 (1.8)
No-contact Control	15	66.8 (6.2)	5	17.0 (2.3)
<u>Experiment 3</u>	(64)			
Younger adults	18	22.1 (3.0)	9	
Older adults	46	67.5 (3.0)	16	

Experiment 2: ANOVA for age- $F(1,45)=2.04$, $p= .14$
Experiment 2: ANOVA for education- $F(1,45)=2.92$, $p= .07$

Supplementary materials

Game Design

NeuroRacer software was developed using the OpenGL Utility Toolkit (GLUT; http://www.opengl.org/resources/libraries/glut/) as a 3D video game to challenge perceptual discrimination in the setting of challenges in visuomotor tracking. The coupling of a constant demand for effective top-down modulation with continuous performance feedback was designed to maximally drive neural plasticity and performance. The road in the game was comprised of a predetermined, equivalent number of "track pieces" such as left and right turns, as well as uphill and downhill pieces that had either a shallow or steep grade (see **Supplementary Figure 10a**). These pieces were presented in a pseudo-randomized order for 2, 2.5, or 3 sec, generating a path for the participant to guide the car on. Given that this was a tracking task, the road went by the car (much like a treadmill) at different rates of speed, with uphill pieces requiring more acceleration (and downhill piece requiring more braking).

There were a total of 200 different road levels, with each level having a minimum and maximum speed that could be attained on that level. Having a range of speeds provided participants the ability to accelerate and decelerate as needed when an uphill/downhill track piece was experienced. Similarly, there were a total of 54 different sign levels: these levels represented the maximum amount of time that a participant had to respond to a presented target, and ranged from 250msec (Sign Level 54) to 1000msec (Sign Level 1). Changes in sign levels corresponded with a 10msec change in this response time window for levels 54 to 19 (600msec), whereas levels 19 to 1 utilized a 25msec change.

The car was able to move in each cardinal direction both on and off the road. Participants were reminded that the driving component was a measure of tracking accuracy by keeping the car at the center of the road i) through an illustration following each run, and ii) by the yellow and red boundaries that formed a box around the road (see **Supplementary Figure 10b)**. The experience was self-paced like a standard video game: participants were able to take breaks between runs and advance to the subsequent run when ready by responding with their right finger. There were an equivalent number of hills and turns (each 2, 2.5, or 3 seconds in length) without any ‘straight’ road intervals to promote constant visuomotor tracking. Tracking ability was measured by the percentage of time spent on the road without hitting road and speed boundaries.

A fixation cross was present on the screen at all times above the car and below the appearing signs. Participants were instructed to look at the fixation cross at all times, and reminded of this after each run (see **Supplementary Figure 10b)**. The fixation cross provided the participant additional information to help their performance on each task: during the perceptual discrimination task, it turned green for 50msec when a relevant sign was responded to within the proper amount of time, or an irrelevant sign was ignored. When either of the aforementioned conditions were not met, it would turn red for 50msec. The fixation cross also provided tracking information, as it would shake when the car was in any of the boundaries. The cross was placed an equal distance between the car and appearing signs, subtended at a visual angle of 1.9 degrees between appearing signs and the car in each experiment.

Neuropsychological battery

All participants 60+ years of age completed a 89 question battery probing for potential neurological condition (e.g. schizophrenia, previous head traumas, stroke), previous and current use of psychotropic, hormonal, cardiovascular and cold medications (participants were excluded for current use of psychotropic and thyroid medications) and if there were any physical or mental conditions that may interfere with daily activities (e.g. migraine headaches, substance abuse, neuropathy). Color blindness was assessed with Ishihara’s Tests for Colour Deficiency. Following this initial screening, older adult participants were then evaluated on 2 separate measures probing for potential cognitive impairments and depression (Mini-Mental State Evaluation (MMSE; minimum score of 26)[10]; Geriatric Depression Scale (GDS)[11]), and 13 neuropsychological tests prior to experimental testing. These 13 tests were subdivided into related domains and composite scores of each were calculated for each of the following domains:

1) Memory Composite- consisted of Logical Memory I[12], Symbol Span[13], the Long-Delay Free Recall measure from the California Verbal Learning Test (CVLT-II)[14], Visual Reproductions I & II[12], Letter Number Sequencing[15]
2) Executive Composite- DKEFS Trails A&B[16], DKEFS Stroop Task[17], Verbal Fluency (Animals[18] and FAS[19]), Wide Range Achievements Test - Reading[20]
3) Motor Evaluation: Grooved Peg Board[21,22,23]

All individuals were required to be within 2 SD of age-matched controls on at least 12 of these 13 tests to be included in the study. This procedure provided a thorough characterization of the cognitive status of each older adult participant in multiple domains while simultaneously ensuring that their cognitive faculties were comparable to that of their age-matched peers. All participants tested within two standard deviations of the normative values established for each of these measures. Critically, each group in Experiment #2 was equally matched on all of neuropsychological tests: A MANOVA testing differences across composite scores of memory, executive components, and motor skills showed that there was no group differences present across these domains ($F(6,80)= .87$, $p= .52$). In addition, separate one-way ANOVAs for each composite score did not reveal any differences ($F(2,45)< 1.67$, $p> .20$).

Surveys

Participants in Experiment 1 were contacted after their *NeuroRacer* training to complete a battery of surveys related to physical health, cognitive health, and lifestyle. The overall score was used for the Cognitive Failures Questionnaire (CFQ)[24], the Need for Cognition Questionnaire (NFC)[25], and the multimedia index[26]. Composite scores were calculated for the BAS pursuit of desired goals[27], physical health and general function from the SF-36[24] (as described by Lacson and colleagues[28]), and self-maintenance and integrative information seeking scores from the Activities Questionnaire from the Victoria Longitudinal Study[29]. These scores were entered into a bivariate partial correlation analysis with the multitasking index controlling for age & education, with a relationship only emerging between the CFQ score ($r(1,122)= .19$, $p= .04$) and the integrative information seeking score assessed via the Victoria Longitudinal Study Activities Questionnaire[7] ($r(1,122)= .21$, $p= .02$).

Experiment 2: *NeuroRacer* multitasking component task analysis

To explore the mechanisms of multitasking cost reduction, we evaluated performance on the *NeuroRacer* component tasks at the Post-training and 6-month visits relative to Pre-training. For both perceptual discrimination ("Sign Only") and visuomotor tracking performance ("Drive Only"), group X session interactions were indicative of a training benefit for both the MTT and STT groups at Post-training that exceeded the NCC group ($F(2,43)> 3.45$, $p< .041$; see **Supplementary Table 1a and Supplementary Figure 4**). Importantly, there were no significant differences between MTT and STT on either measure at the Post-training or 6-month visit ($F(1,27)< 1.77$, $p> .19$ for all comparisons), and both groups showed an equivalent decline in component skills between Post-training and the 6-month mark ($F(2,36)> 1.54$, $p< .22$). Finally, there was also no difference between these groups regarding the improvement on these component skills across their home training sessions (i.e. no group X session interaction present for either 'Sign' or 'Drive' level attained across training: $F< 1.05$, $p> .40$ for each comparison; see **Supplementary Figure 5**). The absence of a significant multitasking cost reduction for STT despite equivalent improvements on the component tasks compared to MTT, as well as the retained cost reduction by MTT despite a decline in component skills, indicates that the multitasking cost reduction exhibited by MTT was not solely the result of enhanced component skills, but a function of learning to resolve interference generated by the two tasks when performed concurrently. These d' cost improvements following training were also not a function of a task tradeoff: a group X session interaction interrogating driving 'cost' [i.e. % of time spent on the road; 'Sign & Drive' performance - 'Drive Only' performance) / 'Drive Only' performance * 100) was not significant ($F(4,72)= 1.31$, $p> .25$), with only a trend towards a main effect of session ($F(2,72)= 2.73$, $p= .10$). While separate ANOVAs revealed no group differences at any time point for driving cost (for each ANOVA, $F< 2.03$, $p> .15$), only the MTT group showed a significant improvement from Pre- to Post-training ($t = 4.83$, $p < .0001$). Finally, we explored the possibility that the observed reduction in multitasking cost do not reflect a strategic trade-off following training. That is, STT participants and MTT participants may have adopted a different strategy, specifically if the STT participants valued the driving task more (and therefore incur higher "cost" on the sign task). To check for this effect, we plotted an ROC-like curve (Attentional Operating Curve (AOC)[30]) which represents “Drive Only”, “Sign Only”, and “Sign & Drive” performance post-training on each respective measure (*d’* and driving accuracy) for each condition. If MTT participants truly learned to multitask better, rather than adopting a tradeoff strategy, then the MTT AOC curve should lie "north-east" relative to the curve for STT participants, which is exactly what was observed (**see Supplemental Figure 18)**.

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