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Adiposity measures predict olfactory processing speed in older adult carriers of the Apolipoprotein E $\epsilon 4$ allele

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Abstract

Objective—The current study investigated the relationship between adiposity and P3 latency.

Methods—Fifty-one adults in two age groups (18-25 and 65+) participated. Odor stimuli were delivered via olfactometer as participants focused on a computer screen. Each stimulus was followed by presentation on the screen of four odor identification choices. Participants attempted identification by button press. Olfactory event-related potentials (OERPs) were recorded. BMI and waist circumference were measured as indicators of adiposity.

Results—In bivariate analyses with all participants included, positive correlations for P3 latency with both BMI and waist circumference were observed, indicating that as adiposity increased latencies also increased. When each age group was separately examined, correlations between adiposity measures and latency remained statistically significant for older adults. Furthermore, ApoE $\epsilon 4$ allele status was examined. Latencies remained positively correlated with adiposity in older adult $\epsilon 4$ carriers; but not in non-carriers.

Conclusions—This study indicates that adiposity predicts olfactory processing speed in older adults, specifically in $\epsilon 4$ carriers.

Significance—The results suggest that olfactory processing speed may be a useful measure for detecting and following the effects of adiposity on brain integrity and cognitive function in those at genetic risk for AD.

Keywords

Apolipoprotein E; Alzheimer's disease; metabolic syndrome; olfactory event-related potentials

INTRODUCTION

Obesity has become a world-wide health epidemic. Globally, nearly 400 million people are obese and one billion are overweight (Kelly et al., 2008). Obesity significantly increases the risk for a number of diseases, including diabetes, hypertension, and heart disease (Malnick

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and Knobler, 2006). Obesity, thus, has grave implications for morbidity and mortality; and is predicted to overtake tobacco as the leading preventable cause of death in the near future (Mokad et al., 2004).

In addition to physiological risks, obesity has a complex relationship with cognition. Obesity is associated with poorer performance on global, executive, and memory measures; and better performance on attention measures (Gunstad et al., 2010). The effects of obesity on cognition were reduced when controlling for hypertension, diabetes, and stroke (Nilsson and Nilsson 2009). This suggests that obesity may have an indirect impact on cognition through the effects of obesity-related comorbidities. Furthermore, past research suggests that obesity may play a role in the development of dementia. Whitmer et al. (2005) reported a 74% greater risk of dementia in those who had obesity at midlife than those who were normal weight, independent of socio-demographics and comorbidities. Obesity is associated with brain volume deficits in patients with Alzheimer's disease (AD) or mild cognitive impairment (MCI) suggesting that adiposity modifies the risk for cognitive impairment as well as having a negative impact on disease outcome in those populations (Ho et al., 2010). Therefore, understanding factors related to the development of obesity is pertinent for overall health.

Food palatability is the strongest predictor of food intake (Mattes, 2008). Smell and taste are highly correlated with food palatability (Sørensen et al., 2003). Smell, particularly retronasal olfaction, is critical to the flavor of food (Murphy, 2008; Murphy et al., 2002). Olfactory loss, present with increased age, may be accompanied by a change in eating habits, along with an overall decrease in food enjoyment (Murphy, 1983, 2008; Murphy et al., 2002; Schiffman, 1994; Schiffman and Pasternak, 1979; Simchen et al., 2006). Individuals with olfactory dysfunction report less satisfaction with food, and consume more to achieve fulfillment (Ferris and Duffy, 1989; Duffy, Backstrand, and Ferris, 1995). Additionally morbidly obese individuals are more likely than moderately obese individuals to demonstrate olfactory dysfunction (Richardson et al., 2004). This suggests that there is a relationship between BMI and olfaction; specifically a higher BMI tends to correlate with a poorer ability to identify odors.

One possible explanation for weight gain is reward compensation. Blum's theory of reward deficiency syndrome hypothesizes that a spectrum of impulsive and addictive behaviors results from a reduction in dopaminergic functioning (Blum, 1996; Noble 1991). Wang et al., (2001) reported obese individuals have lower dopamine D2 receptor availability in the striatum than normal weight individuals. In addition, dopamine antagonists are associated with weight gain and agonists are associated with weight loss (Leddy et al., 2004; de Leon, Diaz, Josiassen et al., 2007). Activation of the nucleus accumbens, a key structure of the brain's reward system, negatively correlates with BMI in older adults tasting sucrose (Green, Jacobson, Haase and Murphy, 2011). Collectively these studies suggest that the reward system may play a vital role in how obesity may develop.

Overall, MRI studies suggest the potential to detect pathological changes and functional activation associated with obesity. There is however a drawback to the high spatial resolution acquired from fMRI, which is the loss of temporal resolution. Electroencephalography (EEG) allows for a higher temporal resolution, measuring in milliseconds rather than seconds. ERP studies can provide data that is complementary to existing MRI findings, but extends our knowledge of how obesity might affect cognitive processes. An ERP study found that obese individuals tended to have a larger attention bias to food pictures than their normal weight counterparts in a satiety condition, whereas normal weight individuals had the larger attention bias in a hungry condition (Nijs et al., 2010). This

study suggests that obese individuals are possibly less sensitive to internal signals of hunger and satiety compared to normal weight individuals.

In spite of studies examining effects of food pictures on ERPs, there is no research that examines how obesity might be related to olfactory event-related potentials (OERPs). Olfaction is associated with food palatability, the strongest predictor of food intake; therefore assessing ERPs in the olfactory modality is important to elucidate the factors related to the development of obesity (Mattes, 2008; Sørensen et al., 2003). OERPs are an objective measure for the sensory-perceptual processing of odor stimuli and show promise as an assessment tool for AD (Morgan and Murphy, 2002). Investigation of the relationship between olfaction and AD is well-motivated; the areas of the brain associated with the early stages of AD are areas that are highly involved in the processing of olfactory information (Braak and Braak, 1992). Raji et al., (2010) found higher BMI was associated with hippocampus and parietal lobe deficits suggesting obesity may increase the risk for dementia in cognitively intact older adults. To the authors' knowledge there is no literature that examines how event related potentials evoked by olfactory stimuli are affected by BMI. Thus the current study's aim is to better understand the role of chemosensory function in the development of obesity and how it may relate to the risk of dementia.

In the current study, the P3 component of the OERP wave, thought to reflect an endogenous potential, was examined (Donchin and Coles 1988). Slower cognitive processing is signified by prolonged P3 latency. Morgan and Murphy (2002) reported that individuals with AD have significantly longer olfactory P3 latencies than their non-demented counterparts. Slower processing of the olfactory information in the AD group may reflect neuropathologies related to higher order processing for olfaction. Furthermore, carriers of the apolipoprotein E (ApoE) $\epsilon 4$ allele, a genetic risk factor for AD, have shown prolonged P3 latency compared to noncarriers, suggesting preclinical neurological changes before probable AD diagnosis (Green and Levey 1999; Murphy et al., 2009). Obesity is associated with brain volume deficits in patients with AD and MCI (Ho et al., 2010). Thus, examining how BMI correlates with olfactory processing allows for better understanding of factors related to the development of obesity and how it may relate to AD.

In the present study, it was hypothesized that individuals with higher BMIs would have longer P3 latencies. Further, we hypothesized that older adults would be more susceptible to these effects than the younger adults. Past OERP studies have found that older adults have significantly longer P3 latencies compared to young adults (Morgan et al., 1997; Murphy et al., 2000). Finally waist circumference was also measured as an additional measure of adiposity. Koster et al. (2008) found that individuals with normal BMI and large waist circumference had higher mortality rates than those with normal BMI and normal waist circumference, suggesting that waist circumference may be a more sensitive health measure. In addition, Whitmer et al. (2005) reported greater risk for developing dementia with central obesity than BMI.

METHODS AND PROCEDURES

Research Participants

Participants were 51 adults from two age groups, Young Adults ($n = 24$, 13 Female, Mean age = 22.6 years) and Older Adults ($n = 27$, 13 Female, Mean age = 71.2 years). Participants were recruited from the general community, from San Diego State University, and from an ongoing subject pool at the Lifespan Human Senses Laboratory. All participants were screened for olfactory function via odor threshold test (Cain, 1989; Murphy et al., 1990) and the San Diego Odor Identification Test (Morgan et al., 1995; Murphy et al., 1994, 2002). Individuals with thresholds or odor identification scores below 3 on these tests were

excluded to eliminate anosmics. Participants were screened for cognitive impairment using the Dementia Rating Scale to eliminate dementia (Mattis, 1976). Subjects with one $\epsilon 4$ allele were categorized as APOE carriers. The research was approved by institutional review and informed consent was obtained from the participants.

Procedure

Adiposity Measures—The anthropometric measures were weight (kg), height (cm), and waist circumference (cm). Weight was measured using a balance scale; height was measured as the distance from the top of the head to the bottom of the feet using a fixed stadiometer. BMI was calculated using the BMI formula (kg/m^2). Waist circumference was measured while the patient was standing using a non-elastic tape measure at the narrowest point between the costal margin and the iliac crest.

ERP Stimulus Presentation—Olfactory stimulation was performed via computer controlled olfactometer incorporating designs of previous olfactometers (Kobal and Hummel, 1988; Lorig et al., 1999, 2000; Morgan et al., 1999; Murphy et al., 1994). Odors were presented utilizing a single stimulus paradigm for 200 msec and an interstimulus interval (ISI) of 30 sec. Participants employed velopharyngeal closure to restrict breathing to the mouth and thereby maintain a constant odorant flow rate (Kobal and Hummel, 1988; Lorig, et al., 1996; Thesen and Murphy, 2000). Fourteen odors (banana, rose, cinnamon, peanut butter, baby powder, mustard, chocolate, pine, lemon, orange, vanilla, coffee, leather, wintergreen) were presented twice each in pseudo-randomized order. Six of these odors (cinnamon, peanut butter, baby powder, mustard, chocolate, coffee) were chosen in order to replicate the most identifiable odors from the San Diego Odor Identification Test (Morgan et al., 1995, Murphy et al, 1994; 2002). The remaining odors were chosen largely for their verified high identifiability, but also their stability in the olfactometer. After each odor presentation the participants were asked to identify the odor via button press from a list of four written options presented on the computer screen in front of them and their responses were recorded electronically. Presentation of odor stimuli was controlled via Compumedics STIM² software.

ERP Recording and Analysis—ERPs were obtained via CompumedicsTM 64-electrode AG/AG/CL sintered Quick-Cap and QuickCell system, amplified via Synamps 2 amplifiers, and recorded on computer hard disk via Neuroscan software package. Electrode impedances were kept below 10 k Ω . EEG recordings from the Pz electrodes site of the international 10/20 system were used for analysis, referenced monopolarly to linked A1 and A2, including ground. Artifactual eyeblink activity was recorded and corrected offline via the Neuroscan software utilizing the Occular Artifact Reduction method within the software. Ongoing EEG activity was recorded throughout the experiment and then trials epoched offline to 500 msec pre-stimulus and 1500 msec post-stimulus. During data collection the data were filtered 0.1-30 Hz. Offline, individual trials were bandpass filtered at 0.1-6 Hz, baseline corrected, and averaged for each participant. Latency windows based on previous OERP studies (e.g. Morgan et al., 1997, 1999) were applied manually by experimenters blind as to condition and then the Neuroscan software selected the largest ERP peaks within those windows, outputting the values into a database for analysis. Latency and amplitude were analyzed at the Pz electrode site. Latencies were measured as the time from stimulus release to the time of peak amplitude of the P3 component. Amplitude was measured from a pre-stimulus baseline to maximum peak amplitude. The current analysis focused on the relationship of the OERP P3 to BMI and waist circumference.

Differences between groups for Age, BMI, waist circumference, and odor threshold scores were investigated with Analysis of Variance.

SPSS was used to conduct bivariate analyses with Pearson Correlations to examine the relationships between adiposity (BMI and waist circumference) and the amplitude and latency of the P3 component.

RESULTS

Demographics

Age, BMI, waist circumference, and odor threshold scores were significantly different between the young and older adults (*See Table 1*). Dementia Rating Scale scores were not significantly different between these two age groups. In addition, odor threshold scores were significantly poorer for ApoE $\epsilon 4$ positive older adults ($p = .005$) than their ApoE $\epsilon 4$ negative peers (*See Table 1*). There were no significant differences between any of the demographic variables for the positive and negative young adults (*See Table 1*).

OERP Latency

As expected, latencies were longer in older adults than in young adults, $F(1,49) = 106.54$, $p < .001$ (*Table 2*). Young adults who were positive for the ApoE $\epsilon 4$ allele also showed shorter latencies than older adults with the ApoE $\epsilon 4$ allele, $F(1,23) = 236.05$, $p < .001$.

OERP and Adiposity

The relationships between the two measurements of adiposity (BMI and waist circumference) and the amplitude and latency of the P3 component were analyzed using bivariate analyses. The analysis of all participants revealed positive correlations between adiposity measures and latency of P3 at Pz, indicating that as adiposity increased latencies also increased i.e., BMI [$r(49) = .511$, $p < .001$], waist circumference [$r(49) = .606$, $p < .001$], (*See Table 3*, *Figure 1*). In further analyses, each age group was separately examined. The correlations between both measurements of adiposity and latency of P3 at Pz remained statistically significant for older adults, i.e., BMI [$r(25) = .382$, $p < .05$], waist circumference [$r(25) = .420$, $p < .05$]. The correlations did not reach statistical significance in young adults (*See Table 3*).

When the data from the older adults were analyzed by genetic status, only the ApoE $\epsilon 4$ positive older adults maintained significant correlations between both measurements of adiposity and P3 latency at Pz, i.e., BMI [$r(14) = .629$, $p < .05$], waist circumference [$r(14) = .625$, $p < .05$] (*See Table 3*, *Figure 2*). Finally, the data for older adults positive for the ApoE $\epsilon 4$ were analyzed separately by gender in an exploratory analysis, females showed strong, significant correlations between measures of adiposity and P3 latency at Pz (*See Table 4*). Correlations approaching, but not reaching significance in males may be the result of reduced power due to small sample in this exploratory analysis (*See Table 4*).

None of the analyses revealed significant correlations between adiposity measures and amplitude, $p > .05$.

Figure 3 shows grand averaged responses for the ApoE $\epsilon 4$ positive (dashed lines) and ApoE $\epsilon 4$ negative (solid lines) older adults, separately for males and females combined (upper graph), males only (middle graph) and females only (lower graph). There was no relationship between adiposity and amplitude. The grand averages shown in Figure 3 might suggest reduced amplitude for the grand averages for the ApoE $\epsilon 4$ positive older females; however, this is likely a result of averaging over responses with different latencies, as there were no differences between ApoE $\epsilon 4$ positive older females and males, with ANOVA conducted on amplitude, $F(1,12) = 0.44$, $p = .52$. The BMI and waist circumference in the ApoE $\epsilon 4$ positive older females were significantly related to P3 latency, suggesting that

different individuals with differing degrees of adiposity produced a range of latencies. Averaging over peaks with different latencies attenuates the apparent average amplitude.

DISCUSSION

This study reveals a positive linear relationship between adiposity and prolonged olfactory latencies in older adults. When analyzed separately, this relationship remained significant only in older adults who were positive for the ApoE $\epsilon 4$ allele, the genetic risk factor for Alzheimer's disease. There were no significant differences in amplitude between groups.

The relationship between olfactory latencies and adiposity in older adults who are positive for the ApoE $\epsilon 4$ allele suggests a negative impact of adiposity on cognitive health for those who are at risk for developing AD. Past ERP studies in multiple modalities have established longer P3 latencies in patients diagnosed with AD versus healthy controls (Marsh, 1990; Morgan and Murphy, 2001; Polich, et al., 1990) and older adults with the ApoE $\epsilon 4$ allele also show longer latencies than those who do not have the $\epsilon 4$ allele (Green and Levey, 1999; Murphy, et al., 2009). The data suggest that there is a preclinical period of AD during which it is possible to observe delayed ERP latencies in groups at risk for developing the disease (Green and Levey, 1999). Furthermore, olfactory P3 latencies have a particularly good sensitivity and specificity in differentiating between ApoE $\epsilon 4$ negatives and positives. Morgan and Murphy (2002) found a correlation between increases in OERP latencies and lower DRS scores in indicating that as the dementia disease process progresses OERP latencies increase. Therefore, we might speculate that the observed relationship between prolonged olfactory P3 latencies and adiposity may be a reflection of decline in olfactory cognitive processing related to preclinical effects of the AD process, and that adiposity exacerbates the disease process for those genetically at risk for AD.

Previous studies have found a relationship between high adiposity and lower brain volumes in both cognitively normal (Raji, et al., 2009), as well as cognitively impaired older adults (Ho, et al., 2010). It is possible that those with higher measurements of adiposity in this study may be showing atrophy related to early stages of degeneration in AD, which may be accelerated in those who are genetically predisposed to AD. A 27-year longitudinal study revealed that people who were obese in middle age had a 74% higher risk of developing dementia, and being overweight increased a person's risk by 35% (Whitmer, et al., 2005). The present relationship between olfactory P3 latency and adiposity, which is more prominent in older ApoE $\epsilon 4$ positive adults, lends further insight into this population that is at the greatest risk for developing AD.

Past studies have implemented a variety of measurements including BMI, hip-waist ratio, and waist circumference to investigate the impact of adiposity on the brain and cognitive health. In this particular study, waist circumference had as strong or stronger an association with olfactory P3 latencies as BMI. These results are in line with research that has found central obesity to be a stronger predictor of developing dementia than BMI (Whitmer, et al., 2007). In females, this may be, in part, related to changes in fat distribution post-menopause (Lee, 2009; Poehlman, 1995). Further research may investigate the sensitivity of different measurements of adiposity and adiposity distribution in determining AD risk and cognitive outcome. The overall impact of adiposity on cognitive function and increased brain atrophy might be related to poor vascular health, reduced cardiovascular fitness or problems with neuroendocrine regulation (Gunstad et al., 2010; Ylikoski et al., 2000). In addition, hypercholesterolemia, diabetes, cardiovascular disease and untreated hypertension are all related to decline in cognitive function (Nilsson and Nilsson, 2009; Ylikoski et al., 2000). These effects may be exaggerated in those who have the ApoE $\epsilon 4$ allele, resulting in earlier and more profound cognitive deficits.

An alternative explanation for the relationship between adiposity and P3 latencies may be related to Blum's (1996) theory of reward deficiency syndrome. Eating can be a very rewarding and reinforcing behavior that activates the dopaminergic reward system in the brain (Volkow et al., 2008; Volkow, Wang, and Baler, 2011; Wang, et al., 2001). Blum theorized that individuals who have low levels of dopamine and dopamine receptors might be more likely to indulge in compensatory overeating. Those who are obese or overweight may overeat as a result of decreased stimulation of the dopaminergic reward system, which can be either congenital, or an effect of chronic overstimulation of D2 receptors from eating (Stice et al., 2008; Volkow et al., 2008; Wang et al., 2001). Past fMRI research using food pictures (Rothenmund et al., 2008) as well as taste stimuli (Green et al., under review; Stice et al., 2008) has found reduced activation in adults with high BMI compared to low BMI in the reward processing areas of the brain. A recent study has linked decreased activation of reward processing in the Nucleus Accumbens and Caudate nucleus during gustatory processing in older adults with high BMI. Green et al., (2011) suggested that because there is a decrease in dopamine function in aging (Volkow et al., 2000), older adults might be at a higher risk for overeating.

When the data for older adults positive for the ApoE $\epsilon 4$ were analyzed separately by gender in an exploratory analysis, females showed strong, significant correlations between measures of adiposity and P3 latency at Pz (See Table 4). Correlations approaching, but not reaching significance in males may be the result of reduced power due to small sample in this exploratory analysis (See Table 4). Past research showing gender differences in frequency of AD (Payami et al. 1996), cognitive decline (Mortensen and Høgh, 2001), and cortical atrophy in $\epsilon 4$ positive older adults (Juottonen et al., 1998). Payami et al. (1996) found a higher frequency of AD in females than males who were heterozygous for the $\epsilon 4$ allele. Mortensen and Høgh (2001) found greater age-related cognitive decline in $\epsilon 4$ positive females than males, specifically in the seventh decade. Finally, an investigation of atrophy in the entorhinal cortex (a primary olfactory processing area, and one of the earliest cortical areas targeted in AD) revealed that female $\epsilon 4$ positive older adults diagnosed with AD showed the greatest amount of atrophy, in comparison to both $\epsilon 4$ positive males and $\epsilon 4$ negative older adults (Juottonen et al., 1998).

Figure 3 shows grand averaged responses for the ApoE $\epsilon 4$ positive (dashed lines) and ApoE $\epsilon 4$ negative (solid lines) older adults, separately for males and females combined (upper graph), males only (middle graph) and females only (lower graph). There was no relationship between adiposity and amplitude. The grand averages shown in Figure 3 might suggest reduced amplitude for the grand averages for the ApoE $\epsilon 4$ positive older females; however, this is likely a result of averaging over responses with different latencies, as there were no differences between ApoE $\epsilon 4$ positive older females and males, with ANOVA conducted on amplitude, $F(1,12) = 0.44$, $p = .52$. The BMI and waist circumference in the ApoE $\epsilon 4$ positive older females were significantly related to P3 latency, suggesting that different individuals with differing degrees of adiposity produced a range of latencies. Averaging over peaks with different latencies attenuates the apparent average amplitude.

Changes in estrogen levels associated with aging and menopause may contribute to gender differences in $\epsilon 4$ positives. Estrogen is a neuroprotective hormone that reduces neural inflammation and stimulates axon growth and dendritic spine density (Turgeon et al., 2006). In addition, hormone therapy (HT) may modulate risk of AD in preclinical postmenopausal women. Studies investigating the interaction between HT and the ApoE allele have found conflicting results. Some studies have found that the genetic risk associated with the $\epsilon 4$ allele can be attenuated for women using HT (Sundermann et al., 2008; Rippon, 2006), while others have found HT may increase risk in $\epsilon 4$ positive women and decrease risk in $\epsilon 4$ negative women (Kaplitt et al., 1996; Mahley et al., 2006; Saunders et al., 2000). These

conflicting results may be related to a necessity for HT to be implemented within a critical time window in order to be effective in reducing cognitive decline (Henderson and Brinton, 2010; Jun Ming et al., 2010). Finally, estrogen is also related to changes in fat distribution in post-menopausal women, resulting in increased central adiposity (Lee, 2009; Poehlman, 1995). This complex relationship between estrogen, adiposity, and genetic risk for AD may underlie the gender differences in olfactory latencies in $\epsilon 4$ positive females and central adiposity. The current study did not have information regarding HT in the participants since this was beyond its original scope. Further research exploring the effect of HT on the relationships between BMI and ERP measures and between waist circumference and ERP measures in older women, and specifically in those who are $\epsilon 4$ positive, would be of interest.

The impact of unhealthy body weight on health outcomes and disease risk has been well documented. Obesity is linked to a plethora of health problems that place a tremendous strain on the health care system and reduce quality of life for overweight individuals (Thompson et al., 1999; Yang and Hall, 2008). Increasing our understanding of the impact that unhealthy body weight can have on olfaction and overall brain function will help us to better understand the relationship between lifestyle and cognitive health. Considering the high prevalence of obesity in our society, and the burden of the obesity-related health problems on the healthcare system, the relationship between unhealthy bodyweight, increased atrophy and dementia prevalence is of great concern. The relationship between adiposity and greater risk of dementia suggests nations that are experiencing rises in obesity rates may also encounter higher incidences of dementia. This may mean that the increase in dementia, and specifically AD, as a result of the imminent increase in the aging population may be greater than previously predicted.

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Highlights

1. Positive correlations for P3 latency with both BMI and waist circumference were observed in older adults at risk for Alzheimer's disease (AD).
2. As BMI and waist circumference increased, P3 latencies also increased.
3. These findings indicate that olfactory processing speed may be a useful measure for detecting and following the effects of adiposity on brain integrity and cognitive function in those at genetic risk for AD.

Figure 1.
P3 latency at the Pz electrode site by a. BMI and b. waist circumference for all participants, separated by age group.

Figure 2. P3 latency at the Pz electrode site by a. BMI and b. waist circumference for older ApoE ε4 positive participants.

Figure 3. Grand averages at the Pz electrode site for ApoE $\epsilon 4+$ and ApoE $\epsilon 4-$ older females and males combined (upper graph), older males only (middle graph) and older females only (lower graph).

Table 1

Age, gender, Body Mass Index, Waist Circumferences, Dementia Rating Scale, and Odor Threshold scores for young and old age groups. Data are mean scores with standard deviations in parentheses.

	Age (years)	Gender (M/F)	BMI (kg/m ²)	Waist C. (cm)	DRS	Odor Threshold
Young (Y) n = 24	22.6 (2.3)	11/13	24.3 (6.1)	82.5 (15.6)	141.3 (3.6)	7.6 (1.0)
Old (O) n = 27	71.2 (4.5)	14/13	29.1 (5.5)	99.5 (13.5)	140.5 (2.7)	5.2 (1.6)
F (1,49) = p	2295 <.001	0.2 .675	8.8 .005	17.4 <.001	0.7 .406	39.7 <.001
Young e4 + n = 11	22.1 (1.8)	6/5	22.3 (4.1)	77.0 (12.4)	139.8 (4.6)	7.6 (0.7)
Young e4 - n = 13	23.1 (2.7)	5/8	25.9 (7.2)	87.1 (17.0)	142.5 (1.8)	7.5 (1.2)
F (1,22) = p	1.1 .306	0.6 .453	2.1 .157	2.7 .116	3.7 .068	0.1 .740
Old e4 + n = 14	70.8 (5.0)	7/7	30.4 (6.2)	102.9 (16.1)	140.6 (2.6)	4.4 (1.2)
Old e4 - n = 13	71.6 (4.0)	7/6	27.7 (4.4)	95.8 (9.2)	140.5 (2.8)	6.0 (1.5)
F (1,25) = p	0.3 .639	0.04 .849	1.6 .214	2.0 .172	0.01 .917	9.3 .005

Table 2

P3 Latency at Pz

	Mean Latency	Standard Deviation
Young Adults ($n = 24$)	696.33	109.69
Older Adults ($n = 27$)	1043.48	128.23
Young Adults 4 + ($n = 11$)	626.55	90.64
Older Adults 4 + ($n = 14$)	1118.14	69.56
Older Males 4 + ($n = 7$)	1115.43	60.58
Older Females 4 + ($n = 7$)	1120.86	82.43

Table 3

Correlations (r values) between P3 latency at Pz and each of the two adiposity measures (i.e., BMI and waist circumference) for all participants, young adults, older adults, older ApoE ϵ 4 positive, and older ApoE ϵ 4 negative adults.

	Body Mass Index vs P3 Latency	Waist Circumference vs. P3 Latency
All <i>n</i> = 51	.511 ***	.606 ***
Young <i>n</i> = 24	.351	.339
Old <i>n</i> = 27	.382 *	.420 *
Old 4 + <i>n</i> = 14	.629 *	.625 *
Old 4 – <i>n</i> = 13	.100	.159

Note.

*
 $p < .05$

**
 $p < .01$

 $p < .001$

Table 4

Correlations (r values) between P3 latency at Pz and each of the two adiposity measures (i.e., BMI and waist circumference) for male and female ApoE ε4 positive older adults.

	Body Mass Index vs P3 Latency	Waist Circumference vs. P3 Latency
Old ε4+ Females (<i>n</i> = 7)	.696 [*]	.899 ^{**}
Old ε4+ Males (<i>n</i> = 7)	.579	.548

Note.

^{*}
p < .05

^{**}
p < .01