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Changes in BMI from young adulthood to late midlife in 1536 Danish men: The influence of intelligence and education

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ABSTRACT

Aims: Intelligence and education have both been associated with body mass index. However, few longitudinal studies have simultaneously investigated the importance of intelligence and education for changes in body mass index (BMI) over time.
Methods: This longitudinal study included 1536 Danish men with information about intelligence, educational level and BMI in young adulthood and BMI 41 years later in late midlife.
Results: Mean BMI increase was 5.1 kg/m^2. Higher intelligence in young adulthood was significantly associated with less gain in BMI. The association attenuated when adjusting for level of education. Higher education was associated with less gain in BMI and these associations remained significant when adjusting for intelligence.
Conclusion: The findings suggest that both intelligence and educational level in young adulthood are associated with changes in BMI from young adulthood to late midlife with education being the stronger predictor of BMI changes across the adult life course.

1. Introduction

Overweight and obesity defined as a body mass index (BMI) of ≥25 kg/m^2 and ≥30 kg/m^2, respectively, are major public health issues associated with elevated risks of developing a wide range of comorbidities such as type 2 diabetes, cardiovascular disease and cancer (Bray, 2004). In 2018, 650 million individuals worldwide could be classified as obese (World Health Organization, 2020) and it has been estimated that 3.4 million individuals die of overweight-related causes each year (Lim et al., 2012). Based on estimates from 2008, over half of the Danish population is overweight and recent evidence suggests that the prevalence of overweight and obesity peaks in late midlife around 60 years of age (Ng et al., 2014), which may indicate the effect of a gradual weight gain across the entire adult life course.

While it is broadly recognized that genetic, social and environmental factors are important determinants of overweight and obesity, there is a growing body of research suggesting that cognitive function, including intelligence, is of importance for weight status (Yu et al., 2010). This may reflect the perspective that stable mental dispositions such as intelligence affect general health and specifically weight through differences in the ability to cope with the obesogenic environment (Kirk et al., 2010). The majority of the studies providing evidence of a link between intelligence and BMI are cross-sectional in design (Yu et al., 2010; Kanazawa, 2014). Some studies have investigated the longitudinal association between intelligence and BMI (Yu et al., 2010; Hagger-Johnson et al., 2012; Lawlor et al., 2006; Chandola et al., 2006; Rosenblad et al., 2012; Halkjaer et al., 2003; Kanazawa, 2013) and report that lower intelligence is associated with higher risk of being overweight or obese later in life, although this association may partly be explained by level of education. Also, several studies do not include a measure of baseline BMI (Lawlor et al., 2006; Chandola et al., 2006; Kanazawa, 2013), why it is somewhat unclear whether the reported predictive value of intelligence for later BMI may be explained by differences in BMI at baseline.

Furthermore, there is some evidence supporting the importance of education for BMI. That is, lower education has consistently been associated with higher BMI in both cross-sectional and prospective studies (Lahti-Koski et al., 2000; Benson et al., 2018; van Lenthe et al., 2000; Ball and Crawford, 2005). However, it is less clear whether these associations are driven by intelligence-related cognitive factors or by non-cognitive factors.

Few longitudinal studies have simultaneously investigated the

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importance of intelligence and education for changes in BMI over time. Halkjær et al. (Halkjaer et al., 2003) investigated whether intelligence in young adulthood (age 19) predicted subsequent BMI changes among Danish men who were followed until middle age. Also, this study found that associations between education and BMI changes persisted after adjusting for young adulthood intelligence. Similar results have been found using childhood intelligence and adulthood education to predict changes in BMI. For instance, a large prospective study reported that childhood intelligence (measured at age 11) was indirectly associated with subsequent BMI gain through educational level in adulthood (Chandola et al., 2006). Thus, together these studies emphasize the role of education in the relation between intelligence and BMI changes. In contrast, other studies find that intelligence is of predictive value for changes in BMI independently of level of education (Rosenblad et al., 2012; Kanazawa, 2013) and that the association of young adulthood education with BMI changes is attenuated when adjusting for intelligence (Rosenblad et al., 2012).

It is generally acknowledged that intelligence and education may be regarded as separate though intercorrelated factors (Halkjaer et al., 2003; Teasdale and Owen, 1984) and it seems that the relative importance of intelligence and education for longitudinal changes in BMI remains unclear. Also, previous longitudinal studies are scarce, investigate the predictive value of childhood intelligence (Lawlor et al., 2006; Chandola et al., 2006; Kanazawa, 2013), have short or widely varying follow-up times (Halkjaer et al., 2003), have no baseline BMI measure and apply absolute adult BMI as outcome (Hagger-Johnson et al., 2012; Lawlor et al., 2006) or do not simultaneously investigate longitudinal effects of both intelligence and education on change in BMI (Lawlor et al., 2006; Chandola et al., 2006). Furthermore, and perhaps most importantly, mean BMI peaks around 60 years of age (Flegal and Troiano, 2000) after which health- and muscle mass-related weight loss begins to appear (von Haehling et al., 2010). However, to our knowledge no study has prospectively investigated associations of both intelligence and education with changes in BMI across a substantial part of the adult life span. Thus, the aim of this study was to prospectively investigate associations of intelligence and education in young adulthood with changes in BMI across a follow-up period of more than 40 years among 1536 Danish men. Based on the existing literature, we hypothesize that both intelligence and education are significantly and inversely associated with BMI changes and furthermore, that education in young adulthood may be a more important predictor of BMI changes across the life course than intelligence.

2. Methods

2.1. Study design and participants

This longitudinal study is based on a subsample of participants from the Lifestyle and Cognition Follow-up Study 2015 (LiKO-15). LiKO-15 is a late midlife follow-up study of men born in 1950–1961 who attended the military conscription in young adulthood. Participants in LiKO-15 were first assessed at the Military draft board examination in 1968–1989 and re-assessed on average 41 years (range: 26.7–47.8) later in 2015–2017.

The LiKO-15 participants included in the present study sample had no previous psychiatric hospital diagnoses and were included as controls in a database established in 2004 in relation to a study on IQ and mental disorders (Urfer-Parnas et al., 2010). The sample has been described in detail elsewhere (Grønkjær et al., 2019). From the aforementioned database, 10,622 men without psychiatric hospital diagnoses and living within 50 km from the follow-up test locations in Greater Copenhagen were invited to participate in LiKO-15. A total of 1,628 (15%) participated in LiKO-15 between September 2015 and June 2017. Information on 79 participants was lost due to technical problems in the military's computer systems and 13 participants had missing values on variables of interest. Thus, the final study sample comprised 1,536 men.

2.2. Body mass index

All Danish men are required to appear before the military draft board when they turn 18 years, only excepting those with disqualifying diseases. Height and weight are assessed at the military draft board examination in young adulthood. At the follow-up in late midlife, height and weight were likewise assessed, this time self-reported by the participants. Using this information, young adult BMI and late midlife BMI was calculated as the weight in kg divided by the squared height in meter. To assess *changes* in BMI, the difference in BMI between young adulthood and late midlife was calculated.

2.3. School education and intelligence

School education was assessed at the military draft board examination. Due to different assessments of school education before and after 1979, the variable was categorized into low (intermediate school, 10th grade or less or craft learned, industrial or trade skilled), medium (including lower secondary school, extended graduation examination or first year of upper secondary school completed) and high (second year of upper secondary school completed or more) school education.

Intelligence was likewise assessed at the military draft board examination. The intelligence test used at the draft board examination is Børge Priens Prøve (BPP), which is a measure of global intelligence comprising four subtests of letter matrices, verbal analogies, number series and geometric figures (Teasdale, 2009). Test scores on BPP have shown to be highly correlated (0.82) with the full-scale IQ of the Wechsler Adult Intelligence Scale (WAIS) (Mortensen et al., 1989). The raw BPP test scores were converted to an IQ scale with a mean of 100 and a standard deviation of 15.

2.4. Statistical analyses

Descriptive statistics were used to investigate participant characteristics, and the bivariate associations between young adult IQ (in four quartiles), year of birth, age at the draft board and the follow-up examinations, education, and BMI in young adulthood were investigated using one-way analysis of variance (ANOVA) for continuous variables and chi-square test for categorical variables (Table 1). Similarly, bivariate associations between school education (low, medium, and high) and covariates were investigated (Table 1a). Pearson's correlation coefficients were used to evaluate retest correlations of height, weight, and BMI assessed in young adulthood and late midlife (Table 2). Multiple linear regression analyses were used to investigate the influence of intelligence and school education in young adulthood on changes in BMI from young adulthood to late midlife (Table 3). Analyses were presented unadjusted (model 1), adjusted for year of birth (model 2), adjusted for BMI in young adulthood and year of birth (model 3), mutually adjusted (i.e. intelligence and school education included in the same model) with year of birth (model 4) and a fully adjusted model (model 5), including year of birth and young adult BMI in addition to intelligence and school education. Year of birth was included as a covariate to adjust for potential generation differences in intelligence and body mass index and to adjust for different ages of participants at the follow-up examination. No statistically significant interaction was found between education and intelligence on changes in BMI when including a two-way interaction term in model 4 and 5. Furthermore, changes in BMI were normally distributed and intelligence was linearly associated with changes in BMI at follow-up. All analyses were conducted in Stata version 14.2 (StataCorp LP, College Station, TX).

3. Results

3.1. Characteristics of the study sample

Table 1 presents participant characteristics in young adulthood

Table 1
Characteristics of the study sample split on young adulthood IQ quartiles (N = 1536).

	Total	Young adulthood IQ quartiles				
		<91 (N = 401)	91-102 (N = 429)	103-112 (N = 372)	≥113 (N = 334)	P-value[a]
Year of birth (mean [SD] [min; max])	1954.4 (3.3) (1950; 1961)	1954.1 (3.4)	1954.8 (3.3)	1954.5 (3.2)	1954.2 (3.4)	0.015
Age at draft board examination (mean [SD] [min; max])	20.3 (2.1) (18; 30)	19.5 (1.3)	20.1 (1.8)	20.6 (2.2)	21.4 (2.5)	<0.001
Age at follow-up examination (mean [SD] [min; max])	61.4 (3.3) (54; 67)	61.7 (3.4)	61.0 (3.4)	61.3 (3.2)	61.5 (3.4)	0.019
Retest interval (mean [SD] [min; max])	41.0 (3.3) (26.7; 47.8)	42.2 (3.5)	40.9 (3.3)	40.7 (3.1)	40.2 (3.2)	0.000
School education (N [%])						<0.001
Low	433 (28.2)	274 (68.3)	115 (26.8)	34 (9.1)	10 (3.0)	
Medium	503 (32.8)	98 (24.4)	197 (45.9)	138 (37.1)	70 (21.0)	
High	600 (39.1)	29 (7.2)	117 (27.3)	200 (53.8)	254 (76.1)	
BMI in young adulthood (mean [SD] [min; max])	21.5 (2.3) (15; 34)	21.6 (2.6)	21.4 (2.3)	21.5 (2.3)	21.4 (2.2)	0.486
BMI in young adulthood (N [%])						0.257
Underweight	121 (7.9)	35 (8.7)	38 (8.9)	29 (7.8)	19 (5.7)	
Normal weight	1303 (84.8)	328 (81.8)	365 (85.1)	320 (86.0)	290 (86.8)	
Overweight	112 (7.3)	38 (9.5)	26 (6.0)	23 (6.18)	25 (7.5)	

[a] Chi-square test of categorical and one-way analysis of variance (ANOVA) of continuous variables.

Table 1a
Characteristics of the study sample split on school education.

	School education			
	Low (N = 433)	Medium (N = 503)	High (N = 600)	P-value*
Year of birth (mean [SD])	1953.7 (3.1)	1954.6 (3.2)	1954.7 (3.5)	<0.001
Age at draft board examination (mean [SD])	19.4 (1.2)	20.1 (1.6)	21.2 (2.5)	<0.001
Age at follow-up examination (mean [SD])	62.0 (3.2)	61.2 (3.3)	61.1 (3.5)	<0.001
Retest interval (mean [SD])	42.6 (3.3)	41.1 (3.2)	39.9 (3.0)	<0.001
BMI in young adulthood (mean [SD])	21.5 (2.6)	21.3 (2.3)	21.6 (2.2)	0.166
BMI in young adulthood (N [%])				0.056
Underweight	41 (9.5)	46 (9.2)	34 (5.7)	
Normal weight	354 (81.8)	422 (83.9)	527 (87.8)	
Overweight	38 (8.8)	35 (7.0)	39 (6.5)	

* Chi-square test of categorical and one-way analysis of variance (ANOVA) of continuous variables.

Table 2
Descriptive results on BMI, height and weight assessed in young adulthood and late midlife (N = 1,536).

	Young adulthood	Late midlife	Change from young adulthood to late midlife	Retest correlation
Body Mass Index (BMI) (mean [SD] [min; max])	21.5 (2.4) (15; 34)	26.6 (4.0) (17; 48)	5.1 (3.6) (−8; 26)	0.47***
Height (mean [SD] [min; max])	179.8 (6.6) (159; 203)	180.5 (6.8) (160; 205)	0.8 (2.4) (−25; 17)	0.93***
Weight (mean [SD] [min; max])	69.5 (9.0) (47; 119)	86.7 (14.0) (52; 167)	17.2 (11.6) (−33; 87)	0.57***

***p < 0.001.

according to IQ quartiles. The men included in the study sample had an average age of 20 years at the draft board examination and an average age of 61 years at the follow-up examination. Higher age at the draft board examination was associated with higher IQ scores in young adulthood, whereas no clear pattern was observed in relation to year of birth and age at the follow-up examination. Participants were almost equally distributed between the three school education groups, where a clear trend of higher IQ with higher school education was observed.

The largest proportion of overweight (BMI≥25 kg/m2) was observed in the lowest IQ quartile group, but the cross-sectional association between young adult IQ quartile and young adult BMI was statistically non-significant both when using BMI as a categorical variable ($p = 0.257$) and as a continuous variable ($p = 0.486$) (data not shown). When examining the bivariate associations between school education and year of birth, age at examinations and BMI in young adulthood, the results obtained with higher school education were highly similar to the results obtained with higher IQ scores (Table 1a).

3.2. Changes in BMI from young adulthood to late midlife

Participants had an average body mass index (BMI) of 21.5 kg/m^2 (SD = 2.4) in young adulthood (Table 2), including 8% underweight, 85% normal weight, and 7% overweight (Table 1). By late midlife, the mean BMI had increased to 26.6 kg/m^2 (SD = 4.0), revealing an average increase of 5.1 kg/m^2 (SD = 3.5) from young adulthood to late midlife (Table 2). The increase in BMI from young adulthood to late midlife was also seen in a change in the distribution within the BMI groups; less men were now underweight (<1%) and normal weight (38%), and the majority of the men was overweight in late midlife (62%) (data not shown). The change in BMI was primarily driven by weight changes, which increased from a mean of 70 kg in young adulthood to a mean of 87 kg in late midlife (mean change in kg = 17.2; SD = 11.6), whereas the mean height only changed marginally (mean change in cm = 0.8; SD = 2.4) (Table 2). The retest correlations of height, weight and BMI from young adulthood to late midlife were 0.93, 0.57 and 0.47, respectively.

3.3. Associations of intelligence, education and changes in BMI

In the unadjusted regression analyses, higher IQ in young adulthood was significantly associated with less gain in BMI from young adulthood to late midlife (Table 3). More specifically, a one-point higher IQ in young adulthood was associated with 0.03 kg/m^2 less gain in BMI from young adulthood to late midlife (95% CI: -0.04;-0.01), corresponding to 0.39 kg/m2 less gain in BMI for a standard deviation increase in IQ in young adulthood. Supplementary Table 1 (s1) presents the standardized effects). The estimated BMI changes associated with IQ were robust as to adjustment for year of birth and young adulthood BMI. In a similar manner, high school education was associated with less gain in BMI from young adulthood to late midlife compared with low school education in

Table 3
Linear regression analyses on the influence of intelligence and school education on changes in BMI from young adulthood to late midlife (N = 1,536).

IQ	Model 1		Model 2		Model 3		Model 4		Model 5	
	- unadjusted		- year of birth adjusted		- BMI adjustment		- mutual adjustment		- full adjustment	
	B (95% CI)	P-value	B (95% CI)	P-value	B (95% CI)	P-value	B (95% CI)	P-value	B (95% CI)	P-value
	−0.03 (−0.04;-0.01)	<0.001	−0.03 (−0.04;-0.01)	<0.001	−0.03 (−0.04;-0.02)	<0.001	−0.005 (−0.02; 0.01)	0.541	−0.01 (−0.02; 0.01)	0.350
School education										
Low	Ref.		Ref.		Ref.		Ref.		Ref.	
Medium	−0.41 (−0.86; 0.04)	0.074	−0.44 (−0.90; 0.01)	0.055	−0.49 (−0.94;-0.04)	0.032	−0.37 (−0.88; 0.13)	0.146	−0.39 (−0.89; 0.11)	0.130
High	−1.31 (−1.74;-0.87)	<0.001	−1.34 (−1.78;-0.91)	<0.001	−1.34 (−1.77;-0.91)	<0.001	−1.23 (−1.80;-0.65)	<0.001	−1.16 (−1.73;-0.59)	<0.001

the unadjusted analyses (B = -1.31; 95% CI: -1.74;-0.87). The estimated BMI changes associated with high school education were also robust as to adjustment for year of birth and young adulthood BMI. For instance, the gain in BMI was 1.34 kg/m^2 smaller in men with high compared with low school education in the 'year of birth'-adjusted analyses (95% CI: -1.78;-0.91). In the analyses where both IQ and school education were included in the models (model 4 and model 5), the estimated BMI changes associated with both IQ and school education were attenuated. However, while the association between IQ and BMI changes became statistically non-significant, high school education remained significantly associated with less gain in BMI. Similar results were found when IQ quartiles were included in the models instead of the continuous IQ variable (Supplementary Table 2 (s2)).

4. Discussion

4.1. Main results

To our knowledge, this is the first study to investigate associations of intelligence and school education on changes in BMI across more than four decades including late midlife where BMI usually peaks. In our sample, average BMI increased with two standard deviations from young adulthood to late midlife and a moderate retest correlation of BMI assessed in young adulthood and late midlife (r = 0.47) was observed, suggesting individual differences in change in BMI. Both higher IQ and educational level were associated with less increase in BMI from young adulthood to late midlife and the associations persisted after adjusting for young adult BMI. When mutually adjusting the IQ and school education variables (by including both factors in the same model), the estimated BMI changes with IQ became statistically non-significant, whereas school education remained significantly associated with BMI changes with high school education predicting less increase in BMI compared with individuals with low school education.

4.2. Comparison with previous studies

Overall, results of the current study are partly in line with previous research although the existing longitudinal evidence of associations of intelligence and education with changes in BMI is based on studies with either shorter or varying follow-ups (Rosenblad et al., 2012; Halkjaer et al., 2003), the use of childhood IQ (Lawlor et al., 2006; Chandola et al., 2006; Kanazawa, 2013) or the use of absolute adult BMI (Lawlor et al., 2006) as opposed to BMI changes. In line with the current findings, the majority of these studies suggest that the associations between intelligence and change in BMI depend on school education (Lawlor et al., 2006; Chandola et al., 2006; Halkjaer et al., 2003). For instance, in a Danish study using data from the Danish draft board examination to obtain information on young adult IQ, Halkjær et al. (Halkjaer et al., 2003) investigated associations of young adult IQ and school education with changes in BMI. The authors reported that both young adult intelligence and school education were associated with changes in BMI at follow-up on average 13 years later (range: 5–23 years). More specifically, a five-unit increase in the intelligence score was associated with a decrease in BMI of 0.19 kg/m^2, which is similar to the effect size found in the current study (B = -0.14 [-0.20;-0.08] for each five-unit increase in young adult IQ). However, when investigated simultaneously, the effect of young adult intelligence became non-significant while the effect of school education remained significantly associated with changes in BMI. Similar findings were reported for a second follow-up 24 years later (range: 16–34 years) (Halkjaer et al., 2003). In addition, a large prospective study with 17,414 subjects (Chandola et al., 2006) found that childhood IQ (measured at age 11) was only indirectly associated with weight gain between age 16 and age 42 and furthermore that this association was mediated by adult educational level and dietary characteristics. In contrast to the findings of the present study, other studies conclude that intelligence is predictive of BMI changes independently of educational attainment (Rosenblad et al., 2012; Kanazawa, 2013). For instance, in a large Swedish study (n = 5,286 men) with a similar design as the design of the current study, IQ in young adulthood significantly predicted BMI change 22 years later even when adjusting for covariates including educational level(11). Furthermore, in that study educational level in young adulthood was not significantly associated with changes in BMI when adjusting for IQ. These inconsistent results may be explained by the larger sample size used in the Rosenblad et al. (2012) study. Also, Rosenblad et al. (2012) did not present results on BMI change according to a continuous IQ variable making a direct comparison between their results and the results of our study challenging.

4.3. Interpretation of the findings

It has been argued that the increasing prevalence of overweight and obesity is a result of individuals responding to the obesogenic environment (Kirk et al., 2010). In this perspective, the significant associations found in the current study between young adult intelligence and educational level (analyzed separately) with changes in BMI during more than 40 years may reflect that both intelligence and education have a direct effect on changes in BMI over time. That is, individuals with either less cognitive ability or lower education are more challenged in responding appropriately to the obesogenic environment. This is supported by findings, that individuals with a certain level of intellectual capacity are more inclined to understand and implement health guidelines in to their everyday lives (Kanazawa, 2013; Gottfredson and Deary, 2004).

However, the finding that associations of intelligence with BMI changes attenuated when adjusting for level of education may indicate that intelligence is indirectly associated with changes in BMI through level of education. Thus, in line with several other studies (Chandola et al., 2006; Halkjaer et al., 2003), it may be proposed that educational level mediates the association between intelligence and changes in BMI such that individuals with higher cognitive ability receive a higher education, which in turn protects against weight gain possibly through the mechanisms discussed above. In the current study, intelligence and education were assessed at the same time, and thus, it is not possible to properly investigate or draw conclusions about the mediating role of education. However, we did perform an additional mediation analysis using the Stata add on program binary mediation. This analysis suggested that most (78%) of the total effect of intelligence was mediated through educational level and that the direct effect of intelligence was non-significant. This is further supported by findings from a Scottish study conducting a path analysis on the Lothian Birth Cohort 1936 reaching across six decades (Hagger-Johnson et al., 2012). The authors found that childhood IQ measured at age 11 was positively associated with adult socioeconomic position including educational attainment, which in turn was negatively associated with BMI late in life (age 68–71). The path model did not include the unmediated direct effect of childhood IQ on late life BMI.

While intelligence is a purely cognitive measure, it may be argued that education reflects cognitive as well as non-cognitive factors. Thus, the finding that associations of educational level with change in BMI persisted even when adjusting for young adult intelligence suggests that non-cognitive factors also play an important role in the association between education and change in BMI across the life course. In this perspective, higher education may promote healthy social relations and environments, which may increase the chances of leading a healthy lifestyle. Furthermore, education may also lead to more secure and higher paying work conditions, which make healthy foods and access to exercise more affordable and reduces the risk of stress (Lunau et al., 2015) and emotional eating. However, it has also been suggested that fixed family factors including neighborhood, parental education, parental socioeconomic background underlie/confound the association between educational attainment and adult BMI (Lawlor et al., 2006; Berry et al., 2010).

Finally, it is possible that the relations between intelligence or educational attainment and BMI are bi-directional. That is, it may be that cognitive ability and education not only affect BMI, but also that BMI affects cognitive ability and educational attainment. In fact, a recent study (Benson et al., 2018) reported that the prospective associations between education and BMI mainly reflected that individuals with higher BMI were less likely to have a higher education. However, in the current study adjusting for young adult BMI did not affect the associations of young adult IQ and educational level with change in BMI.

4.4. Methodological considerations

This study has several strengths including a prospective design, a relatively large study sample, over 40 years follow-up, and measured (as opposed to self-reported) baseline BMI. In addition, to our knowledge this is the first study to have investigated associations of intelligence and education with changes in BMI throughout adulthood (until late midlife), which is crucial as previous research has found that individuals in developed countries typically gain weight until age 60 (Flegal and Troiano, 2000). Furthermore, the timing of the BMI assessments is a major strength of the study. BMI at baseline was measured at an average age of 20 years and thus after childhood- and puberty-related weight changes have occurred. At follow-up BMI was measured at an average age of 61 years, which is before weight loss related to loss of muscle mass or pathological weight loss would be expected. Also, in the current study young adult intelligence was assessed using a well-validated test – the Børge Priens Prøve – which may measure the same underlying characteristics as the widely used WAIS intelligence test (Mortensen et al., 1989). Finally, access to data on BMI measured simultaneously with young adult intelligence and education enabled us to adjust the analyses for young adult BMI and thereby minimize the risk of reversed causality.

Yet, some limitations should be mentioned and considered when interpreting the results of the current study. Firstly, the study sample only included young Danish men who presented at draft board examination. The selection of participants is a concern as women are not required to present for draft board examination. Likewise, men with disqualifying diseases including diabetes are not required to show-up in person and therefore do not complete the intelligence test. Also, the follow-up assessment only included men living in Greater Copenhagen and surrounding areas. The generalizability of the results may therefore be questioned. Furthermore, the study had a relatively modest response rate of 15.3%, and it is therefore likely that participants and non-participants in the LiKO-15 study differ on individual characteristics. In fact, Grønkjær et al. (2019) reported significant differences in level of education between the current study sample and LiKO-15 non-participants, indicating that follow-up study participants represent a socially selected group with a relative large proportion of individuals with upper secondary school education. However, as we found sufficient variance in baseline intelligence scores, educational level and BMI changes, selection factors may not necessarily have influenced the regression estimates though absolute change in BMI may have been underestimated. Also, it should be mentioned that the measure of educational level primarily is a measure of school education and therefore does not encompass education obtained after appearing before the draft board. In contrast to the measured baseline BMI, follow-up BMI was self-reported. This may have introduced a bias if participants underreported their BMI. Yet, we do not expect that this is the case, as it has been suggested that underreporting BMI among men are primarily driven by overreporting height (Merrill and Richardson, 2009) and in the current study, measured height in young adulthood was highly correlated to self-reported height in late midlife ($r = 0.93$). Finally, a large number of factors are likely to influence intelligence, education and change in BMI. In this study, we adjusted for possible confounding factors including age, baseline BMI and mutual adjustment of intelligence and education. However, we did not have baseline information about possible confounders including biological predispositions, smoking, physical activity, diet and alcohol consumption, which may have caused the modest explanatory power of the statistical models (range of explained variance 1.2–4.5 percent). Thus, unmeasured genetic, environmental or lifestyle factors may have influenced the associations, and thus residual confounding is a possibility. As expected in a study with over 40 years follow-up, effect sizes were small, but even small effects of intelligence and education on change in BMI may be important at the population level.

5. Conclusion

The study findings indicate that both young adult intelligence and education are significantly associated with changes in BMI from age 18 to age 61 with educational level being the stronger predictor of BMI changes across the adult life course. Thus, results of the current study may indicate that educational level mediates associations of young adult intelligence with changes in BMI. Furthermore, educational level remained significantly associated with BMI changes after adjusting for young adult intelligence, suggesting that the non-cognitive factors related to education are important for BMI changes during adulthood. However, further research is needed to establish the concrete underlying mechanisms linking intelligence and education to changes in BMI. Nevertheless, the current study contributes with important knowledge to the growing body of research investigating factors contributing to the increasing prevalence of overweight worldwide.

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CRediT authorship contribution statement

Cathrine Lawaetz Wimmelmann: Writing – original draft, Methodology, Investigation. **Marie Grønkjær:** Writing – review & editing, Formal analysis, Methodology, Investigation. **Erik Lykke Mortensen:** Writing – review & editing, Supervision, Methodology, Investigation.

Declaration of competing interest

The authors declare that there is no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.obmed.2021.100334.

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