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Influencing and modifying children's energy intake: the role of portion size and energy density

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Childhood obesity is of concern worldwide. The portion size (PS) and energy density (ED) of food are two major determinants of children's energy intake (EI). Trends towards increasing PS are most apparent and best documented in the USA, where PS of numerous food products have increased in the marketplace over the past three decades, particularly high-energy dense foods. Analyses of population-level dietary surveys have confirmed this trend in children for both in- and out-of-home eating, and a plethora of observational evidence positively associates PS, ED and adiposity in children. A limited number of intervention studies provide clear evidence that children, even as young as 2 years, respond acutely to increasing PS, with some studies also demonstrating the additive effects of increased ED in promoting excessive EI. However, most of the evidence is based on children aged 3–6 years and there is a paucity of data in older children and adolescents. It is unclear whether decreasing PS can have the opposite effect on children's EI but recent acute studies have demonstrated that the incorporation of lower energy dense foods, such as fruit and vegetables, into children's meals down-regulates EI. Although a direct causal link between PS and obesity remains to be established, the regular consumption of larger PS of energy dense foods do favour obesity-promoting eating behaviours in children. Further research is required to establish the most feasible and effective interventions and policies to counteract the deleterious impact of PS and ED on children's EI.

Childhood obesity: Portion size: Energy density: Energy intake

The growing prevalence of childhood obesity over the past decades has become a major public health issue worldwide. Notwithstanding the underlying biology and/or genetic predisposition to obesity, a myriad of environmental factors are associated with the increase of obesity in children. In effect, the pace of technological change has outstripped human evolution and as a consequence, children are ill-equipped to handle the modern food environment, especially in the face of decreasing energy expenditure. Among the factors in the food environment, the contribution of increasing portion size (PS) and energy density (ED: kJ/g), to energy intake (EI) has become the focus of intense investigation.

Food PS have been steadily increasing in parallel with obesity since the 1970s[(1)]. The trends towards increasing PS are the most apparent and best documented in the USA, where PS of numerous food products, especially those of high ED have increased in the marketplace over the past three decades[(2)]. More extensive analyses of nationally representative dietary data in the USA have also confirmed this trend, not only for out-of-home eating, but also for in-home consumption by both adults[(3–5)] and children[(5–7)]. In comparison, there is a

Abbreviations: ED, energy density; EI, energy intake; PS, portion size.
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paucity of trend data on PS in Europe. Limited data from Denmark[8], the Netherlands[9] and the UK[10–12] suggest that trends in PS are mirroring those observed in the USA, albeit that PS tend to be larger overall in the USA[13]. Data from the UK and Ireland show that although the PS of many traditional products have generally remained constant, the range of PS has been extended for many food products, including savoury snacks, bakery products and those sold in fast food establishments[11,14,15].

Large PS, particularly of energy dense foods are highly likely to incite overeating, because they are relatively cheap for food industries to manufacture, and are therefore often seen by consumers as good value for money (e.g. multi- or share-sized packs). Exposure to large serving sizes is now routine and has effectively distorted consumers' perceptions of what an appropriate serving size is. Moreover, the interchangeable use of the terms 'PS' and 'serving size' within existing guidance is confusing and can make it difficult for consumers to decide on an appropriate amount of food to consume[16]. Throughout the current review, PS is defined as the amount of food intended to be consumed by an individual in a single-eating occasion, as opposed to 'serving size', which is the quantity recommended to be consumed in a single-eating occasion (e.g. by a manufacturer on a food label)[17].

The availability of larger food PS of high-energy dense foods is a common characteristic of eating out of the home. Indeed, eating out-of-home is associated with increased EI and fat intakes[18–20], and is an independent risk factor for obesity[21–23]. This is of particular concern given the increased frequency of out-of-home eating over time. For example, in 2004 approximately two-thirds of children from the island of Ireland ate out at least once per week, and food expenditure data demonstrate that this has increased in the past decade[24–27]. Recent research commissioned by *safe*food (the Food Safety Promotion Board, Ireland) has shown that although many restaurants and cafes have increased the provision of healthier options for children in recent years, there is still room for improvement in terms of the availability of PS offered on children's menus, e.g. by allowing children to order half portions from the main menu[28].

The predisposition to overeat in response to large PS appears to be a ubiquitous phenomenon and occurs irrespective of age (child/adult), current weight status, sex and/or degree of dietary restraint or disinhibited eating behaviour[29–33]. In young children food intake has been reported to occur primarily in response to hunger and satiety cues, with early laboratory evidence demonstrating an innate ability of young children to self-regulate their EI[34–38]. This has also more recently been confirmed in the free-living environment[39]. The age, however, at which children become susceptible to over eat in response to large PS remains unclear. There is evidence to suggest that by the age of 1–2 years, children may no longer be immune to the intake-enhancing effects of large PS[40–42]. It should also be remembered that EI is a function of both the PS of a food/beverage, as well as its ED and the frequency of consumption, among other factors[43,44]. Analyses of cross-sectional population level data in the USA have confirmed that over the past three decades, the observed increase in EI by both children over age 2 years and adults has largely been driven by a combination of increased eating frequency and PS[6,44,45].

The purpose of this review is to evaluate the role of PS and ED in influencing and modifying children's EI, and subsequent risk of overweight/obesity.

Portion size

Observational evidence

Although natural hunger-driven eating behaviours are known to regulate the EI of infants and toddlers, environmental cues such as large food PS, have been shown to have the ability to disrupt this innate self-regulation[38,46–49]. In infants and young children (aged less than 11 months), Fox *et al.* (2006)[41] reported a negative relationship between ED and average PS *z*-scores, suggesting that as the ED of diet increased, there was a corresponding down-regulation of food intake. In contrast, no such association was shown in toddlers (aged 12–24 months)[41]. Analysis of data from large-scale dietary surveys[40,50] has also identified that large PS across many food groups are positively associated with obesity in young children. In UK adolescents, an increase in the PS of, and EI from snacks was also observed between 1997 and 2005, particularly for all drinks, crisps and savoury snacks and breakfast cereals[51]. Further research has shown that the PS of meals is positively associated with BMI percentiles in boys aged 6–11 years and in children aged 12–19 years[52], and overall PS is consistently positively associated with both EI and body-weight in children[40]. However, these observational data, cannot establish causality.

Intervention studies

To date nine studies have been conducted in children to assess their responsiveness to increasing PS (Table 1). The majority of these studies have been conducted in the USA, and demonstrate that doubling the PS of a macaroni and cheese entree resulted in a 10–40 % increase in EI[38,42,53–55], whereas a 4-fold increase in entree PS increased the total meal EI by 61 %[33]. These observations were first reported in 5-year-old preschool children, but not in 3-year-old children[38], supporting the self-regulation hypothesis in younger children[46–48]. Subsequent studies, however, have demonstrated significant positive effects of larger PS on EI in children even as young as 2 years[33,42,53,54,56,57]. Moreover, there is evidence to suggest that these effects are sustained for up to 24 h[55].

In the only studies investigating the impact of 'reduced' PS in children, while no change in EI was observed when the PS of the entree decreased by 25 %[58], a positive effect on EI was apparent in other studies when age-appropriate PS were assessed[33,57]. In the study by Smith *et al.* (2013)[57], it is also noteworthy that, unlike the 6-year-old children, the younger children (4-year olds) did not respond to the larger PS by eating

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Table 1. Studies investigating children's energy intake (EI) response to a change in portion size (PS)

	Subjects				Study					
Study	*n*	Age	Gender	Ethnicity	Setting	Design	Duration	PS offered (g)	Δ PS	Δ EI*
Rolls *et al.* 2000[38]	32	3-yr	14B; 18G	78 % white; 6 % Asian; 6 % AA; 9 % other	Preschool children (two classrooms)	Within-subject crossover	1-meal (once/ wk for 3-wk)	3-yr: 150 *v.* 263 *v.* 376	↑2-fold	3-yr: NS
		5-yr			Usual lunchtimes and setting			5-yr: 225 *v.* 338 *v.* 450		5-yr: ↑39 %
Fisher *et al.* 2003[53]	35	3–5 yr	17B; 18G	80 % non-H whites; 11 % Asian; 3 % AA; 6 % H	Preschool children (two classrooms)	Within-subject crossover†	1-meal (once/ wk for 4-wk)	<4-yr: 125 *v.* 250	↑2-fold	↑15 %
					Children's Eating Laboratory			>4-yr: 175 *v.* 350		
Fisher *et al.* 2007[54]	53	5–6 yr	25B; 28G	30 % non-H whites; 38 % non-H blacks; 28 % H; 4 % other	Ethnically diverse children	2×2 within-subject factorial design‡	1-meal (once/ wk for 4-wk)	250 *v.* 500	↑2-fold	↑15 %
					Children's Eating Laboratory					
Fisher *et al.* 2007[42]	75	2–3 yr	44B; 31G	100 % non-H whites	Preschool, at entry to school and elementary school children	Between-subjects design with a within-subject component†	1-meal (once/ wk for 3-wk)	2–3 yr: 200 *v.* 400	↑2-fold	↑13 %
		5–6 yr						5–6 yr: 250 *v.* 500		
		8–9 yr			Children's Eating Laboratory			8–9 yr: 450 *v.* 900		
Fisher *et al.* 2007[55]	59	5-yr	24B; 35G	53 % H; 47 % AA	Preschool children and mothers	Within-subject crossover	24-h (breakfast, lunch, dinner and 1 snack)	NR	↑2-fold	↑12 %
					Children's Nutrition Research Center					
Leahy *et al.* 2008[58]	61	3–5 yr	30B; 31G	63 % non-H white; 31 % Asian; 6 % black/AA	Preschool children (full-day daycare)	Within-subject crossover§	1-meal (once/ wk for 4-wk)	400 *v.* 300	↓25 %	NS
					Usual lunchtimes and setting					
Looney *et al.* 2011[56]	17	2–5 yr	7B; 10G	94 % H; 6 % non-H	Preschool children (full-day daycare)	2×2 within-subject factorial design‖	1-snack (once/ wk for 4-wk)	150 *v.* 300	↑2-fold	↑18 %
					Usual snack time procedure					
Savage *et al.* 2012[33]	17	3–6 yr	7B; 10G	NR	Children in full-day childcare	Within-subject crossover	1-meal (once/ wk for 6-wk)	100 *v.* 160 *v.* 220 *v.* 280 *v.* 340 *v.* 400	↑4-fold	↑61 %
					Eating laboratory dining room					
Smith *et al.* 2013[57]	171	4-yr	93B; 78G	100 % Chinese	Kindergarten students	Within-subject crossover	1-meal (three consecutive days)	105 *v.* 150 (reference) *v.* 195 (±10)	↑2-fold (approx.)	NR¶
		6-yr			Usual lunch setting in the classroom			182 *v.* 261 (reference) *v.* 389 (±10)		

Δ, change; yr, year; B, boys; G, girls; AA, African-American; wk, week; ↑, increase; NS, not significant; H, Hispanics; NR, not reported ↓, decrease.
* Net effect on energy intake (i.e. over total eating occasion/study).
† Study also investigated the effect of self-serve portions on children's energy intake.
‡ Study also investigated the effect of energy density (5·4 and 7·5 kJ/g) on children's energy intake.
§ Study also investigated the effect of energy density (6·7 and 5·0 kJ/g) on children's energy intake.
‖ Study also investigated the effect of energy density (1·8 and 5·0 kJ/g) on children's energy intake.
¶ Study only reported change in food intake (g) which significantly ↓ in 4-yr-old children (179 and 183 *v.* 256 g), but significantly ↑ in 6-yr-old children (252 *v.* 325 *v.* 441 g).

more. In fact, they consumed significantly less food when served the large PS, in comparison with the smaller (reference) PS of the same meal (183 (SD 76) g *v.* 256 (SD 75) g; $P \leq 0.01$)[57].

These short-term studies, although limited in number, provide supportive evidence that from an early age children are susceptible to PS cues. In the short-term children will immediately respond to increasing PS by consuming more, but there is limited evidence to establish whether they will compensate for this at subsequent eating occasions[54,58]. Although evidence from adults suggests larger PS result in a sustained increased in EI for up to 11 d[59,60], no experimental or free-living studies to date have explored the longer-term effects of PS manipulation on the quantity of food consumed in children.

Energy density

Observational evidence

A recent systematic review commissioned by the US Dietary Guidelines Advisory Committee (2010)[61] has concluded that the available evidence consistently supports a positive relationship between ED and bodyweight in children and adolescents as well as adults. The evidence for the association in young people was based on four methodologically rigorous longitudinal studies, whose key strengths were: (1) use of objective measures of adiposity (including dual-energy X-ray absorptiometry or doubly-labelled water) rather than reliance on proxy measures such as BMI; (2) mis-reporting of dietary EI was appropriately adjusted for; (3) ED was calculated by recommended methods that excluded all or most beverages, to avoid attenuation of results[62–65]. The latter issue is of critical importance in evaluating associations between ED and adiposity[65]. These authors convincingly demonstrated that when the calculation of ED included liquids (i.e. water, energy-free and energy-containing beverages), there was no association between ED and the change in adiposity between baseline and follow-up in their study cohort. In contrast, when the ED was calculated based on solid foods, including milk as a food, the ED of the diet at baseline did positively predict the change in adiposity over time. Furthermore, in this study it was the ED of the total diet rather than any particular part of the dietary pattern (e.g. the ED of snacks) that was associated with the change in adiposity[65].

Intervention studies

Studies investigating children's responsiveness to changes in ED are shown in Table 2. Although manipulating the ED of a single snack did not significantly affect children's EI at that eating occasion[56], reducing the ED of an entree has been shown to reduce children's total EI at that meal[54,58,66]. These studies were similar in design to the PS interventions described earlier and the effect of decreasing ED on EI was also of a similar magnitude (17–18 % decrease). Further research has shown that this effect on EI can be sustained when the ED of multiple meals were manipulated over 2 d[67].

Reductions in ED appear to have a positive effect on adiposity in the longer-term, particularly when children and parents are provided with more positively focused messages[68]. Decreases in BMI *z*-scores were significantly greater in children advised to 'increase their intake of healthy foods' compared to those children advised to 'reduce intake of high ED foods' at both 12 (-0.30 *v.* -0.15 *z*BMI units; $P=0.01$) and 24 months (-0.36 *v.* -0.13 *z*BMI units; $P=0.04$)[68]. From a public health perspective this study has revealed key insights about the importance of using positive messages to communicate dietary messages about weight control.

Strategies to reduce children's energy intake

A number of observational studies have associated increasing PS[40,52,69] and ED[70,71] with overweight and obesity in children, and not surprisingly have concluded that addressing such environmental factors is essential if children's food and EI is to be modified appropriately. While all studies that have decreased the ED of children's food agree on the positive effect on children's EI[58,66,67], there is a paucity of data that unequivocally demonstrates the effectiveness of smaller PS.

Additive effects of portion size and energy density on energy intakes

Three studies so far have simultaneously manipulated both the PS and ED of children's food intake[54,56,58] to investigate their independent and/or additive effects on EI (Tables 1 and 2).

In the study by Leahy *et al.* (2008)[58], children's EI at a meal was affected by ED (but not PS). In contrast, Looney & Raynor[56] demonstrated an effect of PS (but not ED) on children's EI at a single snacking occasion. Leahy *et al.*[58] showed that a decrease in ED of a meal (6·7 *v.* 5.0 kJ/g) resulted in a 17 % decrease in EI, irrespective of the PS served[58]. Conversely, Looney & Raynor[56], showed that an increase in the PS of a snack (150 *v.* 300 g) resulted in an 18 % increase in EI, irrespective of the ED of the snack provided. These findings suggest that different strategies to reduce children's EI may be required depending on the type of eating occasion. However, in the study by Fisher *et al.*[54], PS and ED had both independent and additive effects on children's EI. Overall, an increase in both PS (250 *v.* 500 g) and ED (5·4 *v.* 7.5 kJ/g) resulted in a 34 % increased EI at that meal: an effect that was approximately double that reported when the main effects of each factor were analysed individually.

Together this evidence has prompted researchers to investigate novel strategies to reduce ED of children's meals, without compromising on the PS, so that children will compensate by increasing their intake of other foods.

Novel strategies manipulating portion size and/or energy density to modify children's energy intakes

Similar to the findings in studies conducted in adults[72], offering children a large portion of a low-energy dense

Table 2. Studies investigating children's energy intake (EI) response to a change in energy density (ED)

	Subjects				Study					
Study	*n*	Age	Gender	Ethnicity	Setting	Design	Duration	Energy densities offered (kJ/g)	Δ ED	Δ EI*
Fisher *et al.* 2007[54]	53	5–6 yr	25B; 28G	30 % non-H whites; 38 % non-H blacks; 28 % H; 4 % other	Ethnically diverse children Children's Eating Laboratory	2×2 within-subject factorial design†	1-meal (once/wk for 4-wk)	5·4 *v.* 7·5	↑40 %	↑18%
Leahy *et al.* 2008[66]	77	2–5 yr	37B; 40G	NR	Preschool children (full-day daycare) Usual lunchtimes and setting	Within-subject crossover	1-meal (once/wk for 6-wk)	5·9 *v.* 8·4	↓30 %	↓18%
Leahy *et al.* 2008[58]	61	3–5 yr	30B; 31G	63 % non-H white; 31 % Asian; 6 % black/AA	Preschool children (full-day daycare) Usual lunchtimes and setting	Within-subject crossover‡	1-meal (once/wk for 4-wk)	6·7 *v.* 5·0	↓25 %	↓17%
Leahy *et al.* 2008[67]	26	3–5 yr	10B; 16G	60 % white; 32 % Asian; 8 % black/AA§	Preschool children (full-day daycare) Usual lunchtimes and setting	Within-subject crossover	2-d/wk for 2-wk (breakfast, lunch, dinner and 1 snack)	4·7 *v.* 3·9	↓14 %	↓14%
Looney *et al.* 2011[56]	17	2–5 yr	7B; 10G	94 % H; 6 % non-H	Preschool children (full-day daycare) Usual snack time procedure	2×2 within-subject factorial design‖	1-snack (once/wk for 4-wk)	1·8 *v.* 5·0	↑2·8-fold	NS

Δ, change; yr, year; B, boys; G, girls; H, Hispanics; wk, week; ↑, increase; NR, not reported; ↓, decrease; AA, African-American.
* Net effect on energy intake (i.e. over total eating occasion/study).
† Study also investigated the effect of portion size (250 and 500 g) on children's energy intake.
‡ Study also investigated the effect of portion size (300 and 400 g) on children's energy intake.
§ Information only provided for twenty-five out of the twenty-six children.
‖ Study also investigated the effect of portion size (150 and 300 g) on children's energy intake.

first course (e.g. vegetable soup)[73,74] or larger portions of fruit and vegetables with a meal[75,76], were effective strategies in both promoting fruit and vegetable intake and decreasing the ED of children's meals. For example, in the study by Kral *et al.*[75] when the PS of the broccoli and carrots side dish was doubled (75 g *v.* 150 g), children consumed significantly less of the pasta entree. Although the difference in overall EI at the meal was NS, the ED of the foods which children consumed at the meal did significantly decrease with the larger portions of fruit and vegetables (3·97 (SD 0.08) kJ/g *v.* 3.72 (SD 0.08) kJ/g; P=0·005). Moreover, others have shown that reducing the PS of high ED foods (e.g. French fries) and replacing with apple slices[77] or serving dessert alongside the main meal, as opposed to after[78], can attenuate EI irrespective of the PS or choice of main entree. These studies clearly demonstrate the potential to employ more novel strategies for decreasing children's EI, while at the same time not compromising on palatability.

Spill *et al.*[79] also recently demonstrated that incorporating pureed vegetables into multiple meals, to achieve a 25 % decrease in ED, resulted in a down-regulation of preschool children's EI by 12 % (3–5-year-old boys and girls, n 40). Interestingly this reduction in EI persisted over a full day, and moreover, children did not compensate by consuming greater quantities of the un-manipulated snacks and side dishes offered throughout the day, as might have been hypothesised[79].

Overall, these studies demonstrate that simply serving or covertly hiding more fruit and vegetables within children's meals can positively influence children's EI, at the same time as encouraging the consumption of these more healthy foods.

Parental influences

Dietary habits formed in early life are predictive of future eating patterns[80] and evidence suggests the earlier and broader the experience with food, the healthier the child's diet will be[81]. Given that obese parents are more likely to have an overweight/obese child[82,83], arguably this increased risk of childhood obesity is highly likely to be influenced by the epigenetic interactions within the shared family experience, related to both the food and activity environment[84–87].

Research has shown that a coercive feeding approach, e.g. encouraging children to 'clean the plate', may actually have a counterproductive effect on food intake[88–91]. Disruption of children's innate ability to self-regulate their EI and therefore encouraging eating in the absence of hunger has indeed been prospectively linked to an increased risk of becoming overweight, albeit only in girls[92]. Furthermore, this compensation ability has also been shown to decrease with age, particularly in obesity-prone children (i.e. those born to mothers with a pregnancy BMI >66th percentile)[39].

Further research has shown that the amount of food parents or caregivers serve their children is directly related to the amount of food served[49] and is also predicted by the amount they serve themselves[93]. In a repeated-measures cross-sectional study (145 parents and their preschool children), Johnson *et al.* (2014)[93] reported a positive association between the amount of food parents served themselves and the amount of food served to and consumed by their children during three at-home evening meals. These findings add support to studies conducted in the laboratory setting, by showing that in a more natural family environment, children will also respond to larger PS by eating more.

Other environmental cues

Again, similar to findings in studies conducted in adults[94–98], children's PS can also be influenced by food preferences and visual cues, such as self-served portions and the size of tableware.

The self-service of food or beverages requires some form of conscious effort and thought from an individual about how they are going to serve it, as well as the PS they wish to consume. For example, an individual may be perceptually driven to completely fill a cereal bowl, if they perceive an increased level of hunger at the time[99]. Analysis of large-scale survey data from 4966 fifth grade US students (aged 10–11 years) showed that children's liking for higher-energy dense foods (e.g. French fries, meats and potato chips) led to a preference for larger-than-recommended portions compared with that for lower-energy dense foods (e.g. vegetables)[100]. However, the results of experimental studies in this area are equivocal suggesting that self-serving may not provide a 'one-size-fits-all' approach to facilitate the avoidance of overeating in response to larger PS[42,53,101].

The PS of self-served food is also partly influenced by the size of the plate, bowl or glass used[99]. Early research in this area suggests that children perceive taller containers to hold more of a food/beverage than shorter, wider containers[102]. Wansink & van Ittersum[103] subsequently showed that this visual illusion caused children to pour and consume significantly more energy from fruit and soft drinks when they were given a short, wide glass compared with a taller narrow glass (of the same volume capacity). Similar findings have since been confirmed for foods served using different sizes of spoons[104] or onto larger adult-sized dinnerware[105,106], with effects reported to be greater in extraverted compared with introverted children[107].

Conclusions

Positive effects of increased PS and ED on children's food and EI have been observed in children as young as 2 years, and of particular concern, both these factors have been shown to exert independent but additive effects to promote EI. The overwhelming majority of studies manipulating PS or ED in children, however, have been acute, single-eating occasion studies, with only two studies investigating the impact of PS and/or ED on overall food intake for 24 h. Studies have been conducted in both laboratory and more naturalistic settings, for example in the usual classroom setting, but have tended to focus on similar foods/entree meals.

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In general, children tend to eat proportionally more as the PS and/or ED increases, but as most of the evidence is based on children aged 3–6 years, it remains unclear how early young children will begin to overrule their self-regulation of EI when exposed to such environmental triggers. Furthermore, there is a paucity of data in older children and adolescents, particularly conducted across other countries outside of the USA, where the increase in food PS within the marketplace may not be so apparent.

Although a direct causal link between PS and obesity remains to be established, the regular consumption of large PS of energy dense foods do favour obesity-promoting eating behaviours in children. The cumulative evidence relating to strategies to reduce children's EI and outlined in the current review, provides a strong basis for the provision of food PS advice to parents. In addition, such advice should be cognisant of the array of environmental cues consistently reported to inadvertently increase children's food PS, from as young as age 2 years. More emphasis on parental education on PS distortion and appropriate child-sized portions is clearly merited given their role in determining their children's food intake. Current childhood obesity prevention campaigns in the UK[108] and Ireland[109], have highlighted the key importance of offering child-sized portions on appropriately-sized dishware, as well as encouraging lower energy dense snack foods and beverages. More research, however, is required to establish the most feasible and effective intervention and policies to counteract the deleterious impact of PS and ED on children's EI.

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L. K. P. reviewed the literature and wrote the manuscript; T. A. M., M. A. K. and M. B. E. L. provided guidance and commented on drafts of the review.

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