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The effect of a multi-component school-based social network intervention on children's body mass index: a four-arm intervention study

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ABSTRACT

Objective: Schools are considered an important setting for stimulating healthy weight. The current study is unique in examining effects of a multi-component school-based social network intervention on children's body mass index *z*-scores (*z*BMI).

Methods: Four schools were randomly allocated to one of four conditions: a social network intervention using influence agents focusing on water consumption, physical activity, a combination of the two, or a passive control condition. Participants included a total of 201 6- to-11-year-old children (53.7% girls; M_{age} = 8.51, SD_{age} = 0.93). At baseline, 149 (76.0%) participants had a healthy weight, 29 (14.8%) had overweight and 18 (9.2%) had obesity.

Results: Linear mixed effect models indicated that a multi-component school-based social network intervention targeting both water consumption and physical activity was most effective in decreasing children's *z*BMI.

Conclusion: This study suggests that schools can contribute to the intervention of childhood obesity—even without involving the parents—by targeting *both* children's water consumption and physical activity through influential peers, but more research is needed to identify mechanisms of change.

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Childhood obesity; multi-component intervention; social network intervention; physical activity; water consumption

Introduction

Childhood obesity is a serious and prevalent public health issue (NCD Risk Factor Collaboration, 2017). At present, 13.2% of Dutch (Statistics Netherlands, 2021) and 18.4% of American school-aged children (Hales et al., 2017) are estimated to be overweight or obese. Given that childhood obesity increases the risks for subsequent (psychosocial) health problems (Kumar & Kelly, 2017; Weihrauch-Blüher et al., 2019), developing effective childhood obesity interventions has become a high priority. Particularly multi-component interventions addressing diet and physical activity are promising in improving the children's weight (Bleich et al., 2018). As children spend

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a large amount of their time at school, schools are considered an important setting for stimulating healthy weight-related behaviors (Katz et al., 2008; Salvy et al., 2012). Within this study, we assessed the effect of a school-based multi-component intervention on children's weight, combining two promising strategies: replacing the consumption of sugar-sweetened beverages (SSBs) with water (Zheng et al., 2015), and increasing levels of physical activity by emphasizing physical activity enjoyment, one of the most important components explaining sustained physical activity participation (Allender et al., 2006; Rhodes & Kates, 2015).

Children spend a large amount of their time with their peers in school. Peers contribute to the children's social norms about what behaviors are considered typical and acceptable (Herman et al., 2003). Hence, using peer social networks in school-based interventions may be critical for improving children's weight and weight-related norms and behaviors (Salvy & Bowker, 2014; Salvy et al., 2012). In recent years, a couple of social network interventions have been developed in which influential peers (i.e. influence agents) are trained to stimulate healthy dietary intake and/or physical activity among peers. While some studies found that social network interventions improved children's weight-related behaviors (Franken et al., 2018; Sebire et al., 2018; Smit et al., 2020; Smit et al., 2016), others found no intervention effects (Bell et al., 2017; van Woudenberg et al., 2018, 2020). To date, only one previous multi-component social network intervention focused on both sides of the energy balance equation, by targeting the children's dietary intake as well as physical activity (Bell et al., 2017). This study found no behavioral differences between the intervention and control condition after a 10-week intervention period. It might be that this specific multi-component intervention was not effective because it focused on a wide range of weight-related behaviors (i.e. increase consumption of breakfast, fruits and vegetables; decrease consumption of fizzy beverages, sugar, salt and fat; increase physical activity levels) that cannot be easily targeted at school. As a result, the training of influence agents and the health messages influence agents had to transfer to peers might have been too difficult to diffuse informally (Bell et al., 2017). So, it remains unclear whether a more focused multi-component social network interventions may have beneficial effects.

The primary aim of the current study was to test the effects of both single and multi-component school-based social network interventions on children's body mass index *z*-scores (*z*BMI), by targeting specifically children's water consumption and/or physical activity through an innovative peer-based social network approach. To gain more insight into potential underlying mechanisms, we also explored the intervention effects on secondary behavioral weight-related outcomes (i.e. water consumption, SSB consumption and cardiorespiratory physical fitness).

The current multi-component intervention condition importantly differs from the social network intervention of Bell et al. (2017), as the current social network intervention focused on two concrete weight-related behaviors (i.e. water consumption and physical activity 'Born to Move' steps). Importantly, the physical activity behaviors that influential peers stimulated during leisure-time were similar to the 'Born to Move' activities that were given by a certified trainer and that replaced regular sports clinics at school. This way, the current intervention entailed easier trainings and concrete health messages for influence agents to pass on. The 'Born to Move' (dance) activities were taught by a certified instructor and were specifically designed to increase enjoyment and inclusiveness through inclusion of age-appropriate music tracks and fun exercises (see methods, intervention conditions), providing all children the opportunity to participate (Fairclough et al., 2016). In contrast, during regular physical education classes at elementary schools (also in our study) physical education is usually taught by classroom teachers who are not specifically trained to provide these lessons (Fairclough & Stratton, 2006). As such, it is not surprising that previous research has shown that school-based physical activity interventions, including 'Born to Move', can be effective in increasing physical activity and physical activity enjoyment (Burns et al., 2017; Fairclough et al., 2016). As physical activity enjoyment is one of the most important components explaining sustained physical activity participation (Allender et al., 2006; Rhodes & Kates, 2015), it may explain increased activity intensity during class and generalization of physical activity to other (leisure-time) contexts, particularly if such behaviors are promoted by influential peers who are enthusiastic during class and stimulate further use. The increased 'peer-stimulated' use of leisure-time 'Born to Move' activities may also further increase the enjoyment and physical activity intensity during regular 'Born to Move' physical education lessons through feelings of perceived competence (Sterdt et al., 2014). Changing the intensity of activity during school physical education classes is considered important, as reviews suggest that children do not engage in much moderate-to-vigorous physical activity intensity during regular school physical education classes (Fairclough & Stratton, 2006; Tanaka et al., 2018). As such, there is room for improvement.

Effects of our social network interventions were tested in a four-arm intervention study (i.e. multi-component, the single-component interventions focusing on either water consumption or physical activity, and a passive control condition). We expected that the multi-component social network intervention as well as both single-component social network interventions would result in a larger decrease in *z*BMI compared to the control condition. In addition, we hypothesized that the multi-component intervention condition would be more effective in decreasing children's *z*BMI than the single intervention conditions, as multi-component obesity interventions (i.e. diet and activity) are generally more effective than interventions addressing only one component (Bleich et al., 2018). This study is the first testing the effects of single versus multi-component social network interventions on children's *z*BMI and behavioral weight-related outcomes, thereby increasing our understanding of the potential for schools to incorporate children's peer social networks in childhood obesity interventions.

Methods

Participants and procedure

The current study was a four-arm intervention study conducted in primary schools. Schools were randomly allocated to one of four conditions: an intervention focusing on water consumption, physical activity, a combination of the two, or a passive control condition. The study procedure was approved by the Ethics Committee Faculty of Social Sciences (ECSW2016-0905-403) of the Radboud University, Nijmegen, the Netherlands, and has been registered in the Netherlands Trial Register for RCTs (NL5934). A priori power analyses were performed in G*Power 3.1 for an ANCOVA

(Faul et al., 2009). To obtain a power of .80 to detect a medium effect size (*f*=.25) with an alpha level of .05, a total of 179 participants were needed. To account for 10% attrition, we aimed to recruit 200 participants.

In the Autumn of 2016, four primary schools in the Netherlands agreed to participate. Two classrooms out of each school were selected for participation (i.e. second to fifth grade). Caretakers received an information letter through their schools and got the opportunity to withdraw their child from participation. This passive consent procedure was approved by the ethics committee (ECSW2016-0905-403), as participation of all children was necessary to replace regular school sports clinics in some of the intervention conditions. A total of 212 children were invited for the study, of which 210 children were allowed to participate. Of these, nine children were not included in the analyses, because they did not participate in sports clinics due to injuries ($n = 5$), were diagnosed with extreme forms of autism ($n = 2$; experienced difficulties with completing the questionnaires and did not take part in sports clinics), completed no anthropometric measures ($n = 1$), or switched schools during the intervention ($n = 1$). The final sample consisted of 201 children (53.7% girls, $n = 108$), aged 6–11 years ($M = 8.51$, $SD = 0.93$) at baseline. The majority of the children were Dutch (i.e. both parents born in the Netherlands; 80.1%, $n = 106$). Children's *z*BMI at baseline was on average 0.50 ($SD = 0.98$, range: −1.82 to 3.02).

The study took place from November 2016 to April 2017, and included a four-month intervention period. The current study used data collected at baseline (T1; November 2016), mid-intervention (5–6 weeks after baseline, during intervention; T2) and post-intervention (2 weeks after the 4-month intervention period had ended; T3). At baseline, participants completed questionnaires and sociometric measures, and height and weight were measured by one researcher. Directly after the baseline measures, Born to Move sports clinics were implemented in the two conditions targeting physical activity, and reusable water bottles were distributed in the two conditions targeting water consumption. Influence agents were identified using sociometric measures (see Section 2.5.2) and were trained to stimulate water consumption and/or physical activity among their peers. During and after the intervention (at T2 and T3), participants completed questionnaires assessing water and SSB consumption. After the intervention (T3), participants' weight and height were measured as well, and participants were asked to give a description of the aim of the study. None of the children mentioned that the aim was for influence agents to promote water consumption and/or physical activity among their peers.

Intervention conditions

Water consumption

Within the water consumption condition, the *Share* H_2O intervention was implemented, which focuses on promoting water consumption as an alternative for SSBs (Smit et al., 2020, 2021; Smit et al., 2016). One or two weeks after baseline, influence agents received a 90-minute training, emphasizing the benefits of water consumption (e.g. drinking water is good for your skin), encouraging them to consume more water themselves, and providing them with the skills to promote water consumption among peers. During the session they were asked to think about many possible ways through which they could promote water consumption. The training was developed using insights from the self-determination theory (i.e. targeting autonomy, competence, and relatedness to motivate influence agents to drink more water and supporting them in motivating their peers; Deci & Ryan, 2008). As such, it was emphasized that the influence agents should decide for themselves how they wished to encourage their peers to drink more water, although some (important) possibilities were explicitly emphasized and explained (i.e. drinking more water themselves and spreading the health and environmental benefits of water). We also provided all participants with a reusable water bottle to further facilitate the stimulation of concrete water consumption behaviors. Influence agents also attended three 10- to 15-min follow-up sessions (1, 7 and 15 weeks after the training) for support and to ask potential questions. Although we did not explicitly document fidelity, the 'booster' sessions made clear that influence agents were rather active and performed their duties throughout the intervention. For example, trained agents mostly indicated that they regularly refilled their reusable water bottles with water.

Physical activity

Within the physical activity condition, influence agents were trained to stimulate 'Born to Move' (BTM) physical activity among their classmates. This training was modified from the training in the water consumption intervention and involved emphasizing the benefits of physical activity to influence agents (e.g. physical activity is healthy), encouraging influence agents to be more physically active, and teaching them how to promote physical activity among their peers by using BTM activity and enjoyment elements. To support leisure-time BTM activity, all classes in the BTM intervention received four compact discs (CDs) with music from the BTM lessons that could be used at school or at home. This way, children could not only practice the BTM steps during the breaks at schools, but also when playing together at home. Similar as reported for the water condition, we did not explicitly report fidelity and use of BTM CDs. However, during the 'booster' sessions influence agents reported the use of CDs and successfulness in spreading Born to Move steps and enthusiasm, also during mandatory lessons. During mandatory lessons students received official Born to Move (BTM) sports clinics, which were instructed by a certified female instructor (first author) in the school's physical education halls (Les Mills International Ltd, 2013). BTM is a class-based age-adapted physical activity program, emphasizing fun and inclusion and, as such, physical activity enjoyment (Fairclough et al., 2016). The current intervention used the BTM program for 8- to-12 year-olds, incorporating dance, martial arts, games, and yoga movements on age-appropriate music. During the intervention period of 4 months, the BTM lessons replaced the regular school sports hours (i.e. twice a week) and lasted for 45 min per lesson. In total, the children participated in 26 BTM lessons during the intervention. In addition, they received 10 school sports clinics that were already scheduled and could not be replaced.

Multi-component

Within the multi-component condition, the water consumption and physical activity intervention were implemented simultaneously. The same trainings were provided as those in the single intervention conditions, also including the 'booster' sessions. In addition, all classes received BTM lessons twice a week and four CDs with music from the BTM lessons, and reusable water bottles were provided to all participants. As in the physical activity condition, children in the multi-component intervention condition participated in 26 BTM lessons and 10 school sports clinics.

Passive control

Participants within the control condition completed measures at similar moments as the intervention conditions. They received no intervention, but participated in the typical school physical education lessons and sport clinics instead.

Measures

At baseline, children completed questionnaires assessing their age (in years), sex (0 = boy, 1 = girl), and ethnicity (0 = Dutch, both parents born in the Netherlands; 1 = non-Dutch, at least one parent not born in the Netherlands). Moreover, children completed five peer nomination questions, which were used to identify the influence agents. They were asked to nominate by free recall up to five classmates whom they 'regarded as a good leader', 'wanted to be like', 'went to for advice', 'looked up to' and 'respected' (Starkey et al., 2009). In each intervention class, 15% of the boys and 15% of the girls (to ensure sex balance) receiving most nominations in total were selected. A total of 31 children (16 girls) were trained as influence agents (Water consumption, $n = 10$; Physical activity, $n = 10$; Multi-component, $n = 11$).

Anthropometrics

At baseline and at post-intervention, the children's weight and height were measured by a researcher, while children wore light clothing and no shoes. Weight was measured to the nearest 0.1 kg with a digital weight scale (Omron BF511, Omron Healthcare Europe B.V., Hoofddorp, the Netherlands), and height to the nearest 0.1 cm with a mobile stadiometer (Seca 213, Seca GmbH & co. kg., Hamburg, Germany). These measures were used to calculate participants' body mass index (BMI) as weight in kilograms divided by height in meters squared (kg/m^2). BMI was recoded into age- and sex-specific BMI *z*-scores (*z*BMI), using the 1996-–1997 Dutch reference population (Fredriks et al., 2000). Weight categories were calculated using universal BMI cut-offs for children and adolescents (Cole, Bellizzi, Flegal, & Dietz, 2000; Cole, Flegal, Nicholls, & Jackson, 2007).

Water and sugar sweetened beverage consumption

Before, during, and after the intervention period, water- and SSB consumption were measured using self-report questions. Children were asked to report their water, juice, soda, and energy drink consumption on a regular school day and weekend day on a 6-point scale, ranging from 0 (zero glasses per day) to 5 (five or more glasses per day) (Smit et al., 2016). Cans, bottles and packages were also considered as a glass. In line with Smit and colleagues (Smit et al., 2016), we calculated a total score for water consumption by computing the average of the two water consumption items (i.e. water consumption on a school day and on a weekend day), and a total score for SSB consumption by computing the average of the six SSB consumption items (i.e. juice, soda and energy drink consumption on a weekday and on a weekend day). Both measures showed acceptable internal consistency (Water consumption: T1 Cronbach's alpha = .75, T2 Cronbach's alpha=.76, T3 Cronbach's alpha = .77; SSB consumption: T1 Cronbach's alpha=.68, T2 Cronbach's alpha=.75, T3 Cronbach's alpha=.75)

Cardiorespiratory physical fitness

At baseline and after the intervention, the children's cardiorespiratory physical fitness was measured using the 20 m shuttle run test, an acceptable and feasible measure for reliably assessing cardiorespiratory fitness in children (Tomkinson et al., 2019). Children were instructed to run back and forth across a 20 m course following an audio signal. Running pace started at 8.0 km/h, and increased with 0.5 km/h at every one-minute stage (Queen's University of Belfast protocol) (Riddoch, 1990). The test ended when the child stopped because of fatigue, or when the child was unable to reach the 20 m line before the audio signal for two consecutive times. The last completed half-stage was recorded and used as an indicator of cardiorespiratory physical fitness. This measure has been used in previous studies (Mintjens et al., 2019; Ruiz-Hermosa et al., 2018).

Statistical analysis

All data analyses were performed in R (version 3.5.1) (R Core Team, 2021). Differences between intervention conditions in baseline characteristics were examined using analyses of variance and chi-squared analyses for continuous and categorical variables, respectively. Eta-squared effect sizes were calculated for continuous variables, and Cramérs *V* effect sizes for categorical variables. Effect sizes were interpreted as small (η^2=.01; V=.10), medium (η^2 = .06; V=.30) or large (η^2=.14; V=.50), based on Cohen's guidelines (Cohen, 1988).

To test the intervention effect on *z*BMI, we performed a linear mixed-effects model, using the lmer function of the lme4 package (version 1.1.2) with *z*BMI as dependent variable (Bates et al., 2015). The model contained the following fixed effects: Time (continuous, scaled); Condition (sum-to-zero contrasts, Control coded as −1) and the interaction between Time and Condition, and the covariates Age (continuous, scaled), Sex (sum-to-zero contrasts, Female coded as −1), and Ethnicity (sum-to-zero contrasts, Dutch coded as −1). Following the advice of Barr and colleagues (Barr et al., 2013) we created a maximal random-effects structure to account for the repeated measures nature of the data. We included a per-participant random intercept, a per-classroom random intercept, per-classroom random slopes for Time, Age, Sex and Ethnicity, and all possible correlations between the random effects. When performing this model, singularity warnings were encountered, which could not be resolved by changing the optimizer, increasing the number of iterations, or by simplifying the random effects structure. Removing classroom as a grouping variable did resolve the singularity warnings. As the intra-class correlations (ICC) for Classroom was very low (ICC = 0.031), we removed Classroom as a grouping variable, resulting in a random effects structure that only included a per-participant random intercept. *P*-values were determined using Type 3 bootstrapped Likelihood Ratio Tests, as implemented in the mixed function of the afex package (version 0.21.2) (Singmann et al., 2015). Statistically significant interaction effects were further examined with post-hoc analyses, using pairwise comparisons with Tukey adjustments (emmeans package; version: 1.3) (Lenth, 2018).

Additional linear mixed-effects models were performed to test the intervention effect from baseline to post-intervention on the secondary behavioral outcomes, with water consumption, SSB consumption, and cardiorespiratory physical fitness as dependent variables. For water and SSB consumption we also performed additional models testing shorter-term intervention effects (i.e. from baseline to mid-intervention). All additional models were specified in a similar way as the main linear mixed-effect model with *z*BMI as dependent variable (i.e. fixed effects: main effects of Time and Condition and their interaction, and main effect for the covariates Age, Sex and Ethnicity; random effect: a per-participant random intercept).

Deviations from registration

We examined intervention effects on all outcomes as registered (Netherlands Trial Register for RCTs: NL5934), except for two measures (i.e. enjoyment of physical activity and fat mass). Enjoyment of physical activity was left out of the analyses as it is not a weight-related behavior directly influencing children's energy balance. Moreover, fat mass could not be included due to a high degree of missingness caused by errors during measurements.

Results

Descriptive Statistics

Table 1 shows the baseline characteristics of participants in the entire sample and separately for those in each intervention condition. Intervention conditions did not differ regarding sex (small effect; V=.130) and weight categories (small effect; V=0.127), but statistically significant differences between conditions were found for age and ethnicity. On average, participants in the multi-component condition were older than participants in the physical activity and control condition, and participants in the water consumption condition were older than participants in the physical activity condition (medium effect; η^2=.090). Compared to the proportion of Dutch and non-Dutch participants in the total sample, the proportion of non-Dutch participants was higher in the physical activity condition, and lower in the control condition (medium effect; V=.321). We controlled for these demographic characteristics in all further analyses. Moreover, there were some baseline differences for *z*BMI, SSB consumption and cardiorespiratory physical fitness between specific conditions. Specifically, baseline *z*BMI was higher in the physical activity than in the water consumption condition (small effect; η^2=.044). Baseline SSB consumption was higher in the control condition than in the water consumption and physical activity conditions. Given the medium effect size (η^2=.070), results regarding this outcome variable should be interpreted with caution. Further, baseline physical activity was higher in the multi-component than in the physical activity condition (small effect; η^2=.049). Descriptive statistics of the outcome variables per intervention condition across all time points can be found in Table 2.

Table 1. Baseline characteristics of participants in total and by intervention condition.

Variable	Total ($N = 201$)	Water consumption ($N = 44$)	Physical activity ($N = 54$)	Multi-component ($N = 51$)	Control ($N = 52$)	Test statistic	*p*
Age (y)	8.51 (0.93)	8.73 (0.66)	8.15 (0.86)	8.84 (1.07)	8.38 (0.93)	$F(3,197) = 6.469$	<.001
Sex, *n* (%)						$\chi^2(3) = 3.418$	.332
Boys	93 (46.3)	21 (47.8)	20 (37.0)	28 (54.9)	24 (46.2)		
Girls	108 (53.7)	23 (52.2)	34 (63.0)	23 (45.1)	28 (53.8)		
Ethnicity, *n* (%)						$\chi^2(3) = 20.662$	<.001
Dutch	161 (80.1)	36 (81.8)	34 (63.0)	40 (78.4)	51 (98.1)		
Non-Dutch	40 (19.9)	8 (18.2)	20 (37.0)	11 (21.6)	1 (1.9)		
Weight category, *n* (%)							
Healthy weight	149 (76.0)	37 (88.1)	34 (64.2)	36 (72.0)	42 (82.4)	$\chi^2(6) = 11.229$	.082
Overweight	29 (14.8)	4 (9.5)	10 (18.9)	8 (16.0)	7 (13.7)		
Obesity	18 (9.2)	1 (2.4)	9 (17.0)	6 (12.0)	2 (3.9)		
*z*BMI	0.50 (0.98)	0.15 (0.83)	0.73 (1.08)	0.58 (1.04)	0.46 (0.85)	$F(3,192) = 2.968$	.033
Water consumption	2.38 (1.45)	2.05 (1.09)	2.69 (1.65)	2.48 (1.54)	2.27 (1.39)	$F(3,192) = 1.731$	.162
SSB consumption	1.28 (0.81)	1.01 (0.81)	1.19 (0.78)	1.27 (0.85)	1.61 (0.72)	$F(3,193) = 4.857$	.003
Cardiorespiratory physical fitness	4.86 (1.95)	4.90 (2.07)	4.13 (1.81)	5.26 (1.94)	5.09 (1.84)	$F(3,180) = 3.110$	.028

Notes: *z*BMI, body mass index *z*-scores; SSB,Sugar sweetened beverage. Means and standard deviations are presented, unless stated otherwise.

Table 2. Primary and Secondary Outcomes Across Time by Intervention Condition.

	T1	T2	T3
Outcome	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Primary outcome			
*z*BMI			
Water consumption	0.15 (0.83)	–	0.11 (0.90)
Physical activity	0.73 (1.08)	–	0.64 (1.02)
Multi-component	0.58 (1.04)	–	0.41 (1.06)
Control	0.46 (0.85)	–	0.41 (0.89)
Secondary outcomes			
Water Consumption			
Water consumption	2.05 (1.09)	2.51 (1.25)	2.45 (1.09)
Physical activity	2.69 (1.65)	2.64 (1.63)	2.91 (1.66)
Multi-component	2.48 (1.54)	2.80 (1.58)	2.72 (1.49)
Control	2.27 (1.39)	1.95 (1.29)	2.25 (1.49)
SSB Consumption			
Water consumption	1.01 (0.81)	0.93 (0.86)	0.94 (0.78)
Physical activity	1.19 (0.78)	1.31 (0.78)	1.11 (0.98)
Multi-component	1.27 (0.85)	1.19 (0.90)	1.27 (0.84)
Control	1.61 (0.72)	1.15 (0.72)	1.26 (0.63)
Cardiorespiratory physical fitness			
Water consumption	4.90 (2.07)	–	5.45 (2.13)
Physical activity	4.13 (1.81)	–	4.94 (2.07)
Multi-component	5.26 (1.94)	–	5.73 (2.50)
Control	5.09 (1.84)	–	5.35 (2.32)

Notes: *z*BMI,Body mass index *z*-scores; SSB, sugar-sweetened beverage. *M* (*SD*) are based on the raw data.

Table 3. Mixed-Effects Model for zBMI from Baseline (T1) to Post-Intervention (T3) (N = 201).

	*z*BMI		
Fixed effects	χ^2	df	*p*
Age	0.238	1	.643
Sex	3.221	1	.086
Ethnicity	0.279	1	.602
Condition	8.720	3	.039
Time	27.794	1	<.001
Condition × Time	24.786	3	<.001

Note. *z*BMI = Body mass index *z*-scores. Analyses are based on 394 observations.

Primary analyses

The linear mixed-effects model on *z*BMI showed statistically significant main effects of Time and Condition, which were qualified by an interaction between these two variables (see Table 3). Post hoc analyses indicated that *z*BMI statistically significantly decreased in the multi-component (Est. = −0.097, *SE* = 0.014, 95% CI = [−0.126, −0.069]) and control conditions (Est. = −0.044, *SE* = 0.014, 95% CI = [−0.072, −0.016]), but not in the water consumption (Est. = 0.003, *SE* = 0.016, 95% CI = [−0.028, 0.034]) or physical activity conditions (Est. = −0.019, *SE* = 0.014, 95% CI = [−0.047, 0.008]). Further, participants in the multi-component condition showed a steeper decrease in *z*BMI than participants in the water consumption (Est. = −0.100, *SE* = 0.021, $t(197.28) = -4.735$, $p < .001$), physical activity (Est. = −0.078, *SE* = 0.020, $t(197.20) = -3.911$, $p < .001$) and control conditions (Est. = −0.054, *SE* = 0.020, $t(197.21) = -2.660$, $p = .042$). The slope of Time did not differ for the other conditions (water consumption—physical activity: Est. = 0.022, *SE* = 0.021, $t(197.32) = 1.066$, $p = .710$; water consumption—control: Est. = 0.047, *SE*=0.021, *t*(197.33)=2.210, *p*=.124; physical activity—control: Est.=0.024, *SE* = 0.020, *t*(197.25)=1.226, *p*=.611). Thus, these analyses suggest that participants in the multi-component and control condition showed decreases in *z*BMI from baseline to post-intervention, with participants in the multi-component condition showing the steepest decrease.

Secondary analyses

Additional linear mixed-effects models were conducted assessing intervention effects on water consumption, SSB consumption, and cardiorespiratory physical fitness (see Table 4). For water consumption, both short-term and long-term effects were examined. The interaction between Condition and Time was found to be statistically significant for change in water consumption from baseline to mid-intervention (i.e. short-term). Post hoc analyses indicated that participants in the water consumption condition showed a significant increase in water consumption from baseline to mid-intervention (Est. = 0.232, *SE* = 0.109, 95% CI = [0.018, 0.447]), while participants in the other conditions did not (physical activity: Est. = −0.037, *SE* = 0.099, 95% CI = [−0.231, 0.158]; multi-component: Est.=0.162, *SE* = 0.098, 95% CI = [−0.032, 0.356]; control: Est. = −0.174, *SE* = 0.010, 95% CI = [−0.371, 0.022]). Further, participants in the water consumption condition showed a steeper increase in water consumption than participants in the control condition (Est. = 0.406, *SE* = 0.148, *p*=.033). The slope of Time did not differ for the other conditions (all $p > .05$). However, these differential group effects were not found on the longer term (i.e. from baseline to post-intervention), where only the main effect of Time was significant, suggesting an overall increase in water consumption over time (Est.=0.102, *SE* = 0.048, *p*=.035).

For SSB consumption, we also examined both short-term and long-term effects. In the mixed-effects model on SSB consumption from baseline to mid-intervention, the main effects of Condition and Time, as well as the interaction effect were found to be statistically significant. Post-hoc analyses indicated that participants in the control condition showed a significant decrease in SSB consumption from baseline to mid-intervention (Est. = −0.234, *SE* = 0.054, 95% CI = [−.341, −0.128]), while participants in the other conditions did not (physical activity: Est. = 0.065, *SE* = 0.053, 95% CI = [−0.039, 0.170]; water consumption: Est. = −0.033, *SE* = 0.059, 95% CI = [−0.149, 0.083]; multi-component: Est. = −0.040, *SE* = 0.053, 95% CI = [-0.145, 0.065]). Further, participants in the control condition showed a steeper decrease in SSB consumption than participants in the physical activity condition (Est. = −0.300, *SE* = 0.075, $p < .001$). The slope of Time did not differ for the other conditions (all $p > .05$). In the mixed-effects model on SSB consumption from baseline to post-intervention, only the main effects of Time and Condition were found to be significant, suggesting that conditions differed in their level of SSB consumption, and that SSB consumption decreased over time in the full sample (Est. = −0.061, *SE* = 0.027 and *p* = .021).

For cardiorespiratory physical fitness, only long-term intervention effects (from baseline to post-intervention) were available. Only the main effect of Time was found to be significant, indicating an increase in cardiorespiratory physical fitness from baseline to post-intervention in the full sample (Est.= 0.271, *SE* = 0.056, $p < .001$).

Table 4. Mixed-Effects Models for the Secondary Outcome Measures from Baseline (T1) to Mid-Intervention (T2) and Post-Intervention (T3).

	Water consumption						SSB consumption						Cardiorespiratory physical fitness		
	T1 to T2[a]			T1 to T3[b]			T1 to T2[c]			T1 to T3[d]			T1 to T3[e]		
Fixed effects	χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p
Age	0.526	1	.481	0.008	1	.940	2.292	1	.133	0.715	1	.403	3.792	1	.061
Sex	0.128	1	.713	0.212	1	.620	7.930	1	.010	7.031	1	.010	7.659	1	.013
Ethnicity	0.585	1	.450	3.786	1	.068	7.159	1	.015	5.308	1	.021	0.062	1	.802
Condition	5.736	3	.150	3.814	3	.304	9.579	3	.026	13.131	3	.008	2.066	3	.569
Time	0.835	1	.372	4.498	1	.035	4.946	1	.032	5.424	1	.021	22.815	1	<.001
Condition × Time	9.811	3	.027	2.649	3	.464	16.135	3	.002	5.935	3	.118	2.192	3	.529

Note: SSB, Sugar sweetened beverage.

[a]Analysis are based on 201 participants and 392 observations; [b] Analysis are based on 201 participants and 395 observations; [c] Analysis are based on 201 participants and 393 observations; [d] Analysis are based on 201 participants and 396 observations; [e] Analysis are based on 199 participants and 374 observations.

However, the interaction between Time and Condition was non-significant, indicating no further group differences in the effect over time.

Sensitivity analyses

To ensure that intervention effects on *z*BMI, water consumption, SSB consumption, and cardiorespiratory physical fitness were not driven by the influence agents, we performed similar mixed-effect models on the subset of participants excluding the influence agents (*z*BMI: $n = 172$; Water consumption: $n = 171$; SSB consumption: $n = 171$; Cardiorespiratory physical fitness: $n = 169$). For *z*BMI and cardiorespiratory physical fitness, these analyses provided similar findings as the analyses including influence agents. Regarding the long-term effects on water and SSB consumption, the main effect of Time became non-significant when influence agents were excluded. The model assessing short-term effects on water consumption without influence agents showed a statistically significant interaction between Condition and Time. While none of the estimates in the post-hoc analyses reached statistical significance, trends were rather identical to those reported in the analyses including influence agents. Regarding the short-term effects on SSB consumption, the decrease in SSB consumption in the control condition was statistically significantly steeper than all three conditions (results have not been provided, but can be requested from the second author).

Discussion

This study examined the effects of a school-based social network intervention targeting water consumption and/or physical activity on children's *z*BMI (primary aim) and weight-related behaviors (secondary aim). This was the first study testing effects of both single and multi-component social network intervention addressing weight-related behaviors. We found statistically significant decreases in *z*BMI among children in the multi-component intervention compared to the single-component intervention conditions. While children in the control condition also decreased in zBMI, this decrease was smaller than the decrease found in the multi-component social network intervention. In addition to these effects on zBMI, we found some beneficial short-term changes in self-reported water consumption in the water consumption condition, and in SSB consumption in the control condition. On the long-term, however, these self-reported behavioral effects were no longer observed.

The favorable intervention effects on zBMI of the multi-component social network intervention condition—in combination with the null-effects of both single-component interventions—are partly in line with our hypotheses, and support the importance of focusing on *both* sides of the energy balance equation in childhood obesity interventions (Bleich et al., 2018). However, in contrast to our hypothesis, children in the control condition also showed some decreases in *z*BMI over time, although less steep than those receiving the multi-component intervention, whereas children receiving a single component intervention did not. Although we adjusted for potential demographic confounders (i.e. age, sex, ethnicity), important other confounders might not have been eliminated. Moreover, within the area we recruited, schools had started changing their policies to promote healthy weight-related behaviors. As each school was assigned to one intervention condition, it is possible that the effects for *z*BMI found in the control condition school have been induced by changing school policies (e.g. more healthy treats, school vegetable gardening programs, more water taps and an increase in outside breaks). We unfortunately did not record these school policies, so we can only speculate about this explanation. Finally, the higher baseline SSB consumption in the control condition might have facilitated some intervention effects in this condition specifically (versus the water consumption and physical activity condition).

Our findings regarding the multi-component intervention are promising for future school-based interventions, especially because this decrease in *z*BMI was established within only four months and without further parental involvement. Schools, and especially peers, may thus contribute to the prevention and intervention of childhood overweight and obesity by targeting clear, simple, dietary behaviors (i.e. water consumption) and 'enjoyable' activity patterns. As such, we believe that the particularly beneficial change in *z*BMI over time we found in this condition is rather promising. Nevertheless, replication studies including more schools are warranted to ensure adequate randomization.

Surprisingly, secondary analyses on behavioral outcomes did not identify clear potential mechanisms that might explain the different trends in *z*BMI over time across intervention groups. Some short-term effects were found for the consumption of water in the water consumption condition in line with previous research (Smit et al., 2020; Smit et al., 2016), however, clear behavior-related intervention effects underlying the changes in zBMI in the multi-component intervention were not found. Of note, most weight-related behaviors were self-reported. Moreover, we might not have assessed the most eminent weight-related behaviors, explaining lacking behavioral effects. Specifically, the physical activity intervention aimed to make children more active through mainly dance and yoga movements, and may have clearer effects on children's physical activity levels (e.g. steps per day as measured by an accelerometer) than their cardiorespiratory physical fitness (as measured with the shuttle run test in this study). Further, children in the current sample might have been too young to accurately report their dietary intake (Livingstone et al., 2004). Finally, it is possible that temperature timing effects might have played a role, explaining the lack of longer term intervention effects of water consumption. Baseline assessments were collected during the winter and follow-up measures were taken during the spring where children may drink more water anyhow, regardless of intervention condition. To conclude, more objective measures (e.g. direct observation at the school) or measures that are less susceptible to recall bias (e.g. beverage diary with short reference periods), and taking seasonal temperature differences into account, may provide a more accurate view of whether and how this multi-component school-based social network intervention has affected child weight outcomes.

Strengths, limitations and recommendations

The present study has a couple of notable strengths. Firstly, the effect of the multi-component intervention targeting both water consumption and physical activity was compared to the effects of the single-component interventions targeting either water consumption or physical activity, and a passive control condition. Our study was the first to compare such effects of single versus multi-component social network interventions. Secondly, while the previous weight-related social network intervention studies only assessed effects on (self-reported) weight-related behaviors (Franken et al., 2018; Smit et al., 2020; Smit et al., 2016; van Woudenberg et al., 2018, 2020) this study was the first testing intervention effects on objective measures of the children's weight. As such, our zBMI findings are not biased by self-report.

Besides these strengths, some limitations should be addressed. First and foremost, some baseline differences across conditions were present. However, given that the multi-component intervention condition did not differ from the other conditions regarding baseline *z*BMI, we are rather confident to state that our multi-component social network intervention-induced most steepest decrease in zBMI in comparison with the other conditions. Another limitation is that it remains unclear to what extent the specific social network approach contributed to the intervention effects. Specifically, water consumption at schools can be influenced by simply providing participants with reusable water bottles (i.e. targeting 'availability) (Giles et al., 2012; Kenney et al., 2015; Patel et al., 2011). Moreover, the 'Born to Move' lessons may increase physical activity levels through physical activity enjoyment (Fairclough et al., 2016), regardless of effects of influence agents. Nevertheless, we expect increasing intervention effects through our social network component (and influence agents) because of the following two reasons. Firstly, influence agents may stimulate the amount of leisure-time 'Born to Move' physical activity and concrete use of reusable water bottles. Secondly, specifically regarding activity, influence agents may further emphasize enjoyment and more active participation directly (i.e. through class atmosphere) and indirectly (i.e. through increased leisure-time activity further stimulating class activity) during 'Born to Move' mandatory lessons replacing the regular physical education lessons.

We recommend the future research to compare the multi-component social network intervention to the multi-component intervention without the social network component. Other intervention components and mechanisms of change should also be examined, to gain more insight into how (e.g. which social norms and weight-related behaviors changed), for whom (e.g. which children who are more susceptible to peer influence), and which combinations of social network interventions are most effective in decreasing *z*BMI. Specifically, regarding weight-related activity behaviors, future research should include other dimensions of cardiorespiratory physical fitness (e.g. muscle endurance or strength flexibility) that were missed due to the sole focus on cardiorespiratory endurance.

Conclusion

In conclusion, the current study showed that a multi-component school-based social network intervention targeting both water consumption and physical activity was effective in decreasing children's *z*BMI. These findings suggest that schools can contribute to the intervention of childhood obesity—even without involving the parents—by targeting *both* children's water consumption and physical activity through influential peers. Future studies are warranted to replicate these findings and to gain more insight into the key intervention components and mechanisms of change. These insights could be used to further develop and improve school-based obesity interventions.

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Research data

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