Use of an Open-Loop System to Increase Physical Activity

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This study evaluated the effectiveness of an open-loop system that reinforces physical activity with TV watching to increase children’s physical activity. Nonoverweight, sedentary boys and girls (8–12 y) were randomized to a group that received feedback of activity counts + reinforcement for physical activity by providing access to television (F+R, n = 20); or to feedback, no reinforcement (Feedback, n = 20) or no feedback, no reinforcement control (Control, n = 21) groups. Children wore an accelerometer with a count display for 4-months with a 1-year follow-up. F+R reduced TV by 68 min/day and TV time was lower than the Feedback (p < .005) and Control (p < .002) groups. TV time of F+R remained 31 min lower (p < .02) than baseline at 1-year. F+R had a 44% increase in physical activity, which was greater than the feedback (p < .04) and control (p < .01) groups. An open-loop system decreases TV viewing and increases physical activity of children for 4-months. TV of the F+R group remained lower at 12 months, suggesting a reduction in screen-time habits.

Cardiovascular disease, type 2 diabetes mellitus, and osteoporosis have their antecedents during childhood and physically inactive youth have a greater risk of early pathogenesis of these diseases (1,2,4). Establishing physical activity as a habit during childhood is important to maintain physical activity into adolescence and adulthood (11).

Children find sedentary behaviors, such as television (TV) more reinforcing or motivating than physical activity, and in laboratory research would rather work to be sedentary than physically active when given the choice of sedentary or active alternatives (6,18). The greater reinforcing value of sedentary behaviors makes it possible to use them to motivate children to be physically active (21). Using contingent access to sedentary behavior to increase physical activity is an example of behavioral engineering. Behavioral engineering systems can be closed-loop or open-loop in design. Closed-loop systems directly measure the state variable, compare it to a predetermined goal, and if necessary alter the control variable to change the state of the system. An example of a closed-loop system is to require a child to ride a cycle ergometer above a specified work output to activate a TV.
Closed-loop systems can increase physical activity eightfold (20), but are not very flexible. They cannot be adapted to most of the daily activities that children want to engage in at locations outside the home to meet their physical activity goals.

Open-loop systems differ from closed-loop systems in that a human is included in the loop who gathers information on the state variable from a sensor, reviews the data, and makes a decision about what to do next. The benefits of an open-loop system are most apparent when there is immediate feedback of the state variable. An advantage of physical activity monitors to provide immediate feedback of physical activity (state variable) is that the information can be used to set criteria for reinforcement. For example, a child could wear an activity monitor and be given a schedule where every 400 activity counts could be exchanged for 1-hr of sedentary behavior (the reinforcer). Using the display on the monitor the child could view their activity counts at any time to determine the amount of sedentary time that they had earned.

The open-loop system provides maximal flexibility and choice for children to accumulate activity counts. They can choose the time of day, and the mode, intensity and duration of activity that they want to do. This flexibility and control over choice should maximize the reinforcing value of engaging in physical activity. Conversely, restricting access to TV through an open-loop system may increase its reinforcing value (24), with resultant increases in sedentary behavior and reductions in physical activity when the child is no longer being asked to use the open-loop system.

We (19) and then others (13) have shown that an open-loop system can decrease sedentary behavior and increase physical activity for 6–8 weeks, but the system has not yet been tested for longer-term behavioral change. It is not yet known if families are willing to implement the system for longer periods that may help promote changes in TV watching and physical activity habits. Thus, the purpose was to test the effectiveness of an open-loop system to increase children’s physical activity while decreasing their sedentary behavior. Secondary aims were to test the effects of participating in an open-loop system on the zBMI and the relative reinforcing value of physical activity relative to TV watching in children.

Methods

Subjects

Four cohorts were recruited over two years. Two cohorts each were completed during the spring (n = 30) and fall (n = 31) seasons. Participants were recruited through newspaper advertisements and targeted mailings addresses of households in Erie or Niagara counties of New York with at least one child between the ages of 8 and 12 years (InfoUSA, Omaha, NE). Three-thousand addresses were randomly selected for each cohort recruitment period and received a letter that provided information about the study and contact information. Entry criteria for the participating children included an age of 8–12 years, a body mass index (BMI) between the 85th and third percentiles for age and sex, no conditions that would limit physical activity, and 15 or more hours of TV watching per week including TV and video game playing during the school year. Only one child per family could participate. Children could not participate in swimming and/or weight training greater than 5 hr per week. The accelerometer was not waterproof so children whose primary physical
activity was swimming would not have accurate activity data, which would limit use of the reinforcement system. For this same reason extensive weight training was an exclusion criterion because the accelerometer does not record exercise performed with the arms.

A total of 61 families participated in the study. Families of 146 youth were screened by phone and invited to complete a 1-week screening to verify that they met the sedentary and physical activity entry criteria, were willing to complete habit books of their sedentary behavior, wear the activity monitors and operate the TV Allowance units in their home. Twenty-eight children did not complete the screening because the child was no longer interested (n = 4), thought the study was too much work (n = 4), or the child preferred not to participate, but gave no specific reason for their decision (n = 20). Another 57 children completed the screening, but were not accepted into the study because they were either >85th BMI percentile (n = 21), had too little sedentary behavior (n = 24), engaged in too much physical activity (n = 5), or a combination of too little sedentary and too active (n = 5) or were not interested in participating after hearing more specifics about the study or could not follow instructions given during testing (n = 2). No children were excluded due to the swimming or weight training criteria. The remaining 61 children were randomized to feedback of physical activity counts + reinforcement (F+R, n = 20); feedback, no reinforcement (feedback, n = 20) or no feedback, no reinforcement control (control, n = 21) groups. All subjects completed all of the outcome measures at the baseline, 4 month, and 1 year assessments. Parents gave written informed consent and children gave their assent for participation in the study. The University at Buffalo Health Sciences Institutional Review Board approved the study.

**Experimental Design and Procedures**

Children randomized to the F+R group were given feedback through a physical activity monitor (BioTrainer; Individual Monitoring Systems, Baltimore, MD) that displayed their tallied activity counts and were reinforced for physical activity with access to TV. Children recorded their activity counts in a habit book each day and reset the display to zero. Children and a parent returned to the laboratory weekly for the first four weeks so that physical activity during the current week was used to determine TV-time for the following week. To reduce subject burden and to shift more responsibility of implementing the open-loop system to the family, children and a parent returned every two weeks starting at week five. For these weeks, total physical activity across the previous two weeks was averaged to provide a mean counts/week and this mean was used to determine TV-time for the following two weeks. Children were given the goal of 400 activity counts per day and were told that 400 activity counts were equal to 60 min of TV-time. Pilot testing determined that walking on a level grade and average self-selected walking velocity of 5.0 kph children accrued counts at a rate of 371 counts/hour, which was rounded to 400 counts/hour to simplify the conversion of activity counts to TV-time. The validity of this ratio was later confirmed by an independent research group (12).

A TV Allowance unit (Mindmaster Inc., Miami, FL) was placed on each TV in the home and used to budget TV watching. A case manager worked with the parent and child to determine the TV allowance that the parent would program into each TV Allowance unit each week. Each child was provided a unique code that
they could use to activate the TV Allowance. Parents were informed not to restrict TV watching as a form of punishment for the duration of the study. Unused hours from previous weeks could not be added to the hours earned for the current week. When the allowance had run out, it was not available for the remainder of the week.

The feedback, no reinforcement group wore the physical activity monitor with the activity count display turned on. Children were given a goal of 400 activity counts/day, but were not reinforced for physical activity. TV Allowance units were placed on all of the TVs in the home, but there was no contingency for access to TV and no limitation on TV viewing.

For the control group, the accelerometer display was turned off so there was no feedback about physical activity although the monitor was still recording data. TV Allowance units were placed on all of the TVs in the home, but there was no contingency for access to TV and no limitation on TV watching. Children were given a goal of 60 min of MVPA per day.

**Common Treatment Components**

For the first four weeks, families in each group attended separate group sessions to problem solve issues related to protocol compliance and to highlight the importance of attaining activity goals. MVPA was described in terms of physical cues, perceived exertion, and by giving the families a list of physical activities that met the criterion of being at least 3 metabolic equivalents (METs) in intensity. Parents in the F+R group also received information on proper use of the reinforcement system.

Children in all groups were instructed to wear the monitor at least 4 hr per day on week days outside of school and 8 hr per day on weekend days. The child participants were enrolled in several school districts, each with its own policy regarding whether children were allowed to wear an apparatus that resembled a pager device. To standardize the time children could wear the monitor, the decision was made to measure activity after school on school days. This decision was also made to minimize attrition, by reducing the behavioral requirements of the children having to wear an accelerometer all waking hours of every day for 4 months. Anticipating that the children may occasionally forget or not want to wear the accelerometer for a day, they were reimbursed $10 each week if they wore the accelerometer for the required number of hours for at least six days of the week. Children in all groups recorded times that they wore the accelerometer on and took it off each day. All children also recorded times that they engaged in targeted and nontargeted sedentary behaviors in a habit book. Children wore an accelerometer for one-week with the display turned off to determine their activity level at baseline, 4-months and the 1-year follow-up assessment. Children were reimbursed $50 for completing the 1-year follow-up testing. Parents were reimbursed $40 at the 4-month assessment and $10 upon at the 1-year follow-up.

**Measurements**

**Height and Weight**

Child weight was assessed to the nearest 0.5 kg with the subjects wearing light clothing using a calibrated scale. Height was assessed using a SECA stadiometer.
(Hanover, MD). z-BMI was calculated in relationship to the 50th BMI percentile for children based on sex and age.

Physical Activity

Subjects wore a BioTrainer-Pro (BioTrainer; Individual Monitoring Systems, Baltimore, MD) physical activity monitor. Each child was fitted with an appropriate sized belt and wore the monitor at the hip and snug against the body. Parents were instructed to ensure that their child wore the monitor in the appropriate fashion each day. Children who did not go home directly after school took the monitor with them in their backpack and put it on after school hours. With the help of a parent, children recorded the time each occasion they put the monitor on and took it off each day. Data were collected at a sample rate of 10 Hz with an epoch of 1 min. The accelerometer can be initialized at sensitivity levels of 1–40, representing the sensitivity of the monitor in relation to the data display. The sensitivity is set at a lower setting if vigorous activity is anticipated to be measured. Each accelerometer was initialized at a sensitivity of 4 since the study population consisted of children, who are naturally active in frequent bouts of intense activity (3). This allowed viewing of a full range of activity intensities on the computer data display screen. A window was placed over the region of interest on the computer monitor and the total activity counts and time spent in moderate-to-vigorous physical activity (MVPA, defined as > 3 METs) was displayed. The amount of time spent in MVPA was determined by placing a cutpoint line along the y axis at 1.0 g. The cutpoint for MVPA was determined by having the boys and girls wear a Biotrainer Pro accelerometer and walk on a treadmill for 3 min each at 56.4 m·min⁻¹, 69.6 m·min⁻¹, and 85.8 m·min⁻¹ while oxygen consumption (mL·kg⁻¹·min⁻¹, Vmax 29 metabolic cart, Sensormedics, Yorba Linda, California) was measured and averaged over the last 30 s of each stage. Linear regression was used to determine the g value at 3 METs (10.5 mL·kg⁻¹·min⁻¹) for each child and this averaged 0.86 g. The MVPA cutpoint was rounded-up to 1.0 g because the software increments the cutpoint in 0.25 g units. The treadmill test was also used to perform a validation of the Biotrainer Pro. The average Biotrainer Pro g value across the 3 min of each exercise stage and the average oxygen consumption across the last 30 s of each stage were regressed and produced an average r of 0.96 ± 0.07.

Sedentary Behaviors

Targeted and total sedentary time was determined using a habit book. Children recorded time spent in targeted (television) and nontargeted sedentary behaviors (recreational computer use, hand-held videogames, reading) in a habit book. Total measured sedentary time was the sum of targeted and measured nontargeted sedentary behaviors. Children also recorded times that the accelerometer was put on and taken off throughout the day. The habit book and physical activity data were compared for agreement in that activity counts should only occur while the child reported wearing the accelerometer and that sedentary behavior and physical activity occurred during times with relatively low and high counts, respectively. Disagreement between the habit book and accelerometer were probed with the child and parent. Children in the F+R group recorded their activity counts at the end of each day to monitor the TV-time allowance earned that day.
Relative Reinforcing Value (RRV) of Physical Activity

To determine the physically active and sedentary alternatives to be used for the RRV task, children sampled and rated their liking of three physical activities [cycle ergometer (CatEye USA, model EC 1600, Boulder CO), stepper (Precor USA, model 718e, Woodinville, WA), twist-&-ski (NordicTrack)] and cartoon vignettes (Sponge Bob Square Pants, Jimmy Neutron, Fairly Odd Parents) using a 10 cm visual analog scale (VAS). The physical activity and cartoon with the greatest liking score were used in the RRV task. Children then sampled pressing a handheld counter at a rate of one press per second using a metronome to keep the rate of button presses constant. Children then completed a questionnaire choosing whether to complete button presses to earn time to watch their most highly rated cartoon or physical activity. The questionnaire consisted of 16 questions that presented a choice between the number of presses they were willing to perform to gain 10 min access to the cartoon or to the physical activity. For access to cartoons the schedule for button presses started at 20 and increased by 20 presses with each question until a total of 320 button presses was required for question 16. For physical activity the schedule for button presses remained constant at 20 for all questions. To increase accuracy of responding children were instructed that they would have to pull a number out of a bag that corresponded to one of the questions and then have to perform the button pushes and then the activity that they circled for that question. The questionnaire was scored as the schedule at which a child switched from a willingness to respond for watching their most highly rated cartoon to working for engaging in their most highly rated physical activity. The less work the child was willing to perform to gain access to cartoons was interpreted to indicate a greater RRV of physically active versus sedentary alternatives. The questionnaire has been validated against a computer controlled laboratory concurrent schedules choice task in children (10) and predicts free-living physical activity in youth (18).

Data Analysis

Group baseline differences were tested with two-way ANOVA with gender and group treated as between variables. Analyses were carried out using separate repeated mixed multilevel regression models to assess alterations in sedentary behaviors, physical activity, RRV of physical activity, and zBMI. The models included main effects of gender (boy, girl), group (F+R, feedback, control), and week (0, 1, 2, 3, . . . 15, 52) and interactions. Time (weeks) was treated as a fixed categorical effect to estimate means and test specific hypotheses. Significant main and interaction effects were explored with contrast statements. Mixed models and contrasts were run using the SAS Proc Mixed protocol (version 9.2, SAS Institute, Cary, NC).

Results

There were no gender ($p ≥ .48$) or group ($p ≥ .44$) differences for any of the demographic or physical characteristics at baseline (Table 1). As shown in the upper panel of Figure 1, there was a significant group by time interaction ($p < .005$) for TV time. TV time of the F+R group was on average 43% (68 min) lower ($p < .001$)
**Table 1 Subject Demographics and Physical Characteristics**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th></th>
<th>Feedback, no reinforcement</th>
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<td>n = 9</td>
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<tr>
<td>Age (yr)</td>
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<td>10.5 ± 1.6</td>
<td>10.5 ± 1.6</td>
<td>10.4 ± 1.4</td>
<td>10.5 ± 1.5</td>
<td>11.2 ± 1.1</td>
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<tr>
<td>Height (cm)</td>
<td>149.1 ± 11.0</td>
<td>144.3 ± 4.8</td>
<td>142.2 ± 13.8</td>
<td>142.2 ± 13.9</td>
<td>141.2 ± 10.2</td>
<td>148.5 ± 8.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>42.1 ± 9.6</td>
<td>36.6 ± 5.9</td>
<td>35.0 ± 10.9</td>
<td>37.7 ± 9.8</td>
<td>37.9 ± 10.0</td>
<td>39.3 ± 7.6</td>
</tr>
<tr>
<td>BMI %ile</td>
<td>64.2 ± 14.9</td>
<td>52.8 ± 23.1</td>
<td>45.3 ± 30.3</td>
<td>62.8 ± 17.0</td>
<td>63.1 ± 33.4</td>
<td>47.4 ± 25.7</td>
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<tr>
<td>z-BMI (kg/m²)</td>
<td>0.4 ± 0.4</td>
<td>0.1 ± 0.7</td>
<td>-0.2 ± 1.0</td>
<td>0.4 ± 0.5</td>
<td>0.4 ± 1.1</td>
<td>-0.1 ± 0.8</td>
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<tr>
<td>SES</td>
<td>47.4 ± 6.0</td>
<td>45.4 ± 10.8</td>
<td>42.4 ± 10.6</td>
<td>48.8 ± 11.0</td>
<td>44.6 ± 11.8</td>
<td>46.0 ± 12.5</td>
</tr>
</tbody>
</table>

Data are mean ± SD

SES: socioeconomic status, z-BMI: standardized body mass index
Figure 1 — Television use (top panel) and total measured sedentary behavior (bottom panel) of the feedback plus reinforcement open-loop group (circles); feedback, no reinforcement group (triangles); and no feedback, no reinforcement control group (squares) groups during the intervention and at the 52 week (1-year) follow-up. Data are mean ± SE.
than at baseline during the intervention and 55% lower ($p < .001$) than baseline at 4 months. TV time remained 21% (31 min) lower ($p < .02$) than baseline at the 1-year follow-up. TV time of the Feedback ($p \geq .64$) and Control ($p \geq .08$) groups did not differ from baseline at the 4 months or 1-year follow-ups. There was also a main effect between groups ($p < .001$) as the F+R group engaged in 66% less ($p < .001$) TV time than the Feedback group and 85% less ($p < .001$) TV time than the Control group. The Feedback and Control groups did not differ ($p \geq .31$) for TV time.

As shown in the lower panel of Figure 1, The F+R group had a differential reduction ($p < .006$) in total measured sedentary time. The F+R group participated in 43–81% (58–116 min) fewer minutes of sedentary behavior than the Feedback and Control groups, with the greatest group differences occurring during weeks 7 and 8. Total sedentary behaviors of the F+R group were on average 28% (52 min, $p < .001$) lower than baseline during the intervention and 42% lower ($p < .001$) than baseline at the 4 month follow-up. At the 1-year follow-up, total sedentary behaviors of the F+R group did not differ ($p \geq .10$) from baseline. Total sedentary behaviors did not differ from baseline at the 4-month (feedback $p \geq .58$, control $p \geq .62$) or 1-year follow-up (feedback $p \geq .41$, control $p \geq .55$) for the other groups. As a main effect, the F+R group engaged in less (main effect: $p < .005$) total measured sedentary behavior time compared with the Feedback ($p < .02$) and Control ($p < .002$) groups. The Feedback and Control groups did not differ ($p \geq .48$) for total sedentary behaviors.

The groups did not differ ($p \geq .30$) for physical activity at baseline. As shown in Figure 2, physical activity differentially increased ($p < .02$) between groups during the intervention. For the F+R group physical activity was on average 44% greater ($p < .05$) than baseline, with the greatest increase of 76% above baseline occurring during weeks 7 and 8. Increases in physical activity also occurred in the Feedback and Control groups, but not as consistently, with smaller increases above baseline occurring at weeks 7–9 for the Feedback and Control groups. Physical activity was greater ($p < .007$) than baseline at the 4-month assessment for the F+R group. Physical activity at 1-year did not differ ($p \geq .12$) from baseline for any group. There was a significant ($p < .02$) main effect for physical activity as it was greater in the F+R group than the Feedback ($p < .01$) and Control ($p < .05$) groups, which did not differ ($p \geq .48$) for total physical activity.

There was also a significant ($p < .02$) group by time interaction for MVPA. For the F+R group MVPA was greater ($p < .05$) than baseline during all treatment weeks except week 5 with an average increase of 34% above baseline and with the greatest increase of 55% above baseline occurring during weeks 7 and 8. For the F+R group, MVPA was 26% greater ($p < .01$) than baseline at the 4 month assessment, but not different ($p \geq .36$) than baseline at the 1 year assessment. Increases in MVPA also occurred in the Feedback and Control groups, but not as consistently, with increases above baseline occurring at weeks 4, 7, 8 and 10–14 for the Feedback group and weeks 7–9, 11, 12 and 14 for the Control group. MVPA at the follow-up assessments were marginally greater than baseline in the Feedback (4-month $p \geq .05$, 1-year $p \geq .26$) and Control (4-month $p \geq .08$, 1-year $p \geq .07$) groups. There were no significant main ($p \geq .27$) or interaction ($p \geq .54$) effects for the reinforcing value of physical activity relative to TV watching. There were also no significant main ($p \geq .71$) or interaction ($p \geq .08$) effects for zBMI.
Discussion

This study took advantage of innovations in behavioral engineering by testing whether an open-loop control system could increase the physical activity of children. The open-loop system consisted of feedback of physical activity counts and reinforcement (F+R) for accumulating activity counts. F+R increased physical activity by 44–76% and produced a 68 min/day reduction in TV-time during the...
intervention that remained reduced by 31 min/day at the 1-year follow-up. Thus, 
F+R increased physical activity while simultaneously decreasing sedentary behav-
iors in children for 4-months. Previous field trials of open-loop systems (13,19) 
also demonstrated increases in activity and reductions in TV. However, these were 
shorter-term interventions of 6–8 weeks. With a 4-month intervention, the current 
study was the first longer-term test of the efficacy of an open-loop system to main-
tain increases in physical activity and reductions in sedentary behavior of children.

Though there was an increase in physical activity of the F+R group across 
the entire intervention, it peaked during weeks 7 and 8. These weeks coincided 
with spring break and winter breaks from school. The intervention was completed 
during the school year so that the children had relatively consistent schedules and 
similar amounts of time to be sedentary or physically active. However, this natural 
variation in available free time during the experiment revealed that F+R may be 
more effective when children have large amounts of free-time. These results may 
have important implications for increasing children’s physical activity behavior 
during longer breaks such as summer vacation given that the open-loop system 
maintained physical activity for 4-months.

The present study also extends previous research by including a feedback only 
group. Feedback produced inconsistent increases in physical activity that were on 
average 18% smaller than observed for the F+R group during the intervention. All 
groups, including the Feedback group received information on physical activity 
intensity and how to exercise safely. Interestingly, a short-term, 5-day study, of 
children demonstrated that feedback from pedometers plus information on how to 
increase their daily steps produced increases in physical activity (5).

While physical activity increased with F+R, both TV- and total sedentary-time 
were consistently reduced during the F+R intervention. Thus, children did not 
fully substitute their loss of TV time with time spent engaged in non-TV sedentary 
behaviors. Rather, some of this time was devoted to increases in physical activity. 
Moreover, TV viewing time remained reduced by 31 min in the F+R group at the 
1-year follow-up suggesting that the reduction in TV time may have become a 
habit. The substitution of TV time with physical activity appears to be a strength 
of the open-loop system (13,19) that is not observed when the behavioral treatment 
consists only of reducing TV and other sedentary behaviors (7,8). Indeed, reducing 
children’s TV viewing time by 25–50% is associated with minimal increases in 
physical activity (7,8). Greater TV watching predicts the development of obesity 
in children (14). Reducing TV time could help prevent excess weight gain (9,17) 
and open-loop systems may be an important behavioral engineering strategy to 
effect such change in the TV watching. However, effects of an open-loop system on 
children’s adiposity have been mixed. The current study found no effect on adipos-
ity, but the previous two field studies of the open-loop system observed reductions 
in adiposity that were associated with reductions in TV watching (13,19). These 
previous studies included overweight and/or obese youth, while the current study 
included only normal weight youth, so zBMI reductions were not anticipated.

An advantage of the open-loop system is that it is simple to implement. The TV 
Allowance technology used in the system reduces the need for parenting skills to 
 promote behavior change. Most behavioral interventions that target children require 
parent involvement to apply the program and to establish a home environment that 
fosters and maintains the desired behavioral change. To increase the likelihood that
a pediatric behavioral intervention will be effective, it should be easy to employ so that parents with limited time to devote to behavioral change strategies and with limited training in behavioral change can carry-out the intervention. TV-time of the F+R group was consistently reduced during the intervention, including during school vacations. This demonstrates that parents were able to successfully implement the open-loop system for the 4-months of the intervention. Moreover, there was no attrition in any study arm, including the F+R arm, and all families returned for the 1-year follow-up. All parents and children indicated that they agreed or strongly agreed that overall, they enjoyed being part of the program.

Another advantage of an open-loop system is that children are placed in control over how much TV time they are able to earn and how they want to expend their allowance. This may reduce conflict between the parent and child when access to sedentary behaviors are reduced. If the child wants more TV time, they can do the physical activity of their choice and earn the amount of sedentary time that they want. Choice over physical activity choices is an important factor for maintaining adherence to an exercise program (15,16,23). If a child cannot do the physical activities of their choice, they will be less likely to choose to be physically active.

A potential concern in using TV as a reinforcer and decreasing access to TV is that it may increase the reinforcing value of TV. When arbitrary reinforcers (e.g., points, tangible goods, behaviors) are used to motivate children to adopt healthier behaviors, there is often the issue of selecting reinforcers that children are motivated to obtain, and program efficacy is a direct function of identifying powerful reinforcers. TV-based behaviors were used as the reinforcers in the open-loop system because they naturally occur at a high rate and are very reinforcing. For instance, when the button press requirements for access to TV-time and physical activity were equal in the current study, nearly every child chose to work for access to TV-time. According to disequilibrium theory (24), the reinforcing value of a behavior is increased when the rate of that behavior is decreased below baseline rates. As detailed above, one of the consequences of using TV watching to reinforce children for being physically active was that this contingency reduced the rate of engaging in TV watching. This provided the potential for increasing the reinforcing value of TV watching. However, there was no change in relative reinforcing value of physical activity to TV watching for any study group. It is likely that the use of naturally occurring high rate behaviors as reinforcers reduced implementation problems associated with reinforcer selection. The approach of using naturally occurring sedentary reinforcers instead of money or gifts may also reduce problems with generalizability over time when the intervention and reinforcement is stopped.

There are some study limitations that may limit the generalizability of the results. The study was limited to nonoverweight children, which limited effects on adiposity change and limits generalization to nonoverweight children. However, previous studies have demonstrated the efficacy of F+R to increase physical activity and reduce sedentary behavior in overweight youth (13,19). The present study was novel because it focused on normal weight, but sedentary youth. There were also methodological limitations. Children did not wear the accelerometers all day. The child participants were enrolled in several school districts, each with its own policy regarding whether children were allowed to wear an apparatus that resembled a pager device. To standardize the time children could wear the monitor, the decision was made to measure activity after school on school days. Children
in all groups had to wear the accelerometers everyday for four months. Providing some time each day that the accelerometer did not have to be worn likely helped to prevent attrition that would have occurred if the children were mandated to wear the accelerometer every waking hour of every day for four months. These wear times provided for testing of the open-loop system in that they offered the children sufficient opportunity to earn sedentary reinforcer time during the day while reducing the burden of wearing the monitor everyday for 4 months. However, it is possible that the children had compensatory reductions in activity when not wearing the accelerometers.

The behavioral engineering technology focused on modifying sedentary behavior in the children’s homes. Children in the F+R group could have watched TV when playing at their friends’ houses. When TV viewing did occur outside of the family home, we asked children in each study group to record it in their habit books. Each child’s accelerometer file was downloaded and carefully compared with their habit book. If the accelerometer depicted a sedentary period and it was not adequately described in the habit book, the child was asked to account for this time.

For the follow-up evaluations, children were asked again to wear accelerometers. There was the possibility for children, to be reactive to the follow-up testing. Though activity was not increased at 1-year, it was not decreased either so that potential age-related declines in physical activity were not observed (22). However, the mean age of children in the current study was 10.5–11 years. Age-related declines in activity are much more dramatic at age 13–18 years (22). Finally, children were compensated for their study participation. The compensation was for meeting time wearing the accelerometers, not for sedentary or active behavior change, reducing the possibility that monetary incentives were responsible for the observed behavior changes.

In summary, this study contributes to public health by demonstrating that an open-loop system can increase physical activity while simultaneously decreasing sedentary behavior in children for 4-months. TV time of the F+R group remained lower than baseline 8-months after finishing the intervention suggesting a reduction in TV habits. The natural variation in children’s free-time that was afforded by school vacations suggests that the open-loop system may be most effective at increasing physical activity when children have much free-time if constraints on TV remain in place.

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References


