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ScienceDirect

Journal of Exercise Science & Fitness 13 (2015) 35–41

www.elsevier.com/locate/jesf

Original article

Tracking energy balance in adolescents: Levels of compliance, energy flux, and learning

Senlin Chen [a,*], Xihe Zhu [b], Gregory J. Welk [a], Youngwon Kim [a]

[a] Department of Kinesiology, Iowa State University, Ames, IA, USA
[b] Department of Human Movement Sciences, Old Dominion University, Norfolk, VA, USA

Received 23 June 2014; revised 7 January 2015; accepted 27 January 2015
Available online 6 March 2015

Abstract

Background/Objective: Advancing knowledge about energy balance (EB) is important for helping to reverse the obesity epidemic in many modern societies. This study examined adolescents' experience and perception of using an objective self-monitoring tool (SenseWear armband; SWA) and a portable diet journal to track EB for 7 days.
Methods: Forty-five 6th grade students in a midwestern state of the United States [Caucasian: $n = 34$, 76%; age: 11.7 ± 1.8 years; body mass index (BMI): 20.84 ± 3.94] participated in the study. The SWA, diet journal, and semistructured individual interview were used to measure energy expenditure (EE) and physical activity (PA), energy intake (EI), and perception of the experience, respectively. Mixed methods were used to analyze quantitative and qualitative data.
Results: It was found that the participants were physically active over the week (moderate-to-vigorous PA: 218.06 ± 26.50 minutes per day). Both SWA (% of wearing time: 85 ± 5%) and diet journal (days of using: 5.58 ± 2.15 days), especially the latter, were found to be under-used. A conceptual model depicting the adolescents' experience and perception was established based on the results.
Conclusion: The study indicates that the majority of adolescents were able to effectively use the SWA and the diet journal to track EB over time. Qualitative observations revealed that tracking EI and EE with these tools provided a valuable, experiential way for youth to learn about EB. The findings support the continued exploration of self-monitoring EB for promoting knowledge and awareness about EB among adolescents.

Keywords: Energy balance education; Energy expenditure; Energy intake; Mixed methodology

Introduction

Lifestyles in modern affluent societies are characterized by excess consumption and sedentariness.[1,2] The state of high energy intake (EI) in conjunction with low energy expenditure (EE) leads to positive energy balance (EB; i.e., EI > EE), which, when prolonged, causes accumulation of body fat. The World Health Organization reported that the global prevalence of overweight and obese children has grown from about 5% in 1990 to 7% in 2012 but with a dramatically higher increase in certain countries such as the United States (US) and China.[3] Surveillance data show that one-third of American adolescents are overweight or obese.[4,5] Obesity is a risk factor for associated morbidities and mortality[3,6] and can track from childhood into adulthood if not intervened.[7,8] In light of this public health crisis, it becomes necessary to educate adolescents on how to live an energy-balanced lifestyle and incorporate preventive strategies early in life.[6,9,10] The concept of EB is the key to understanding the mechanism of weight fluctuation and needs to be timely conveyed to youth.[11,12] Robust evidence based on a large sample ($N = 3003$) of participants who have lost at least 30 lbs body weight

* Corresponding author. Iowa State University, 255 Forker Building, Ames, Iowa 50011-1160, USA.
E-mail address: slchen11@iastate.edu (S. Chen).

http://dx.doi.org/10.1016/j.jesf.2015.01.001

demonstrated that frequently monitoring one's body weight is associated with significantly less weight gain.[13] The individuals with less frequent monitoring were found to have increases in EI from fat and in disinhibition (but a decrease in cognitive restraint) for their weight management behaviors than the more frequent monitoring individuals.[13] Modern societies are infused with a variety of technologies for people to regularly and conveniently monitor their status of EE (e.g., pedometers, accelerometers, indirect calorimeters), EI (e.g., diet journals, software tools), and EB (e.g., smartphone or computer applications). As time advances, most of these modern technologies have become more affordable and accessible by consumers, and many seem to have a reasonably good measurement accuracy.[14,15]

Actively interacting with these technologies not only enables people to show healthy weight management behaviors in the long term, it may also enhance EB education, especially among youth. Using advanced self-monitoring tools such as the SenseWear armband (SWA; BodyMedia, Pittsburg, PA, USA) and a diet journal can potentially help adolescents understand EB and strategize for achieving the EB status.[16] SWA is an advanced self-monitoring tool to track EE. In clinical settings, it has demonstrated a high efficacy in facilitating weight reduction among overweight or obese adults.[17–19] Specifically, it served as an effective tool for providing instant electronic feedback that helped the users become aware of their daily EE status; this elevated awareness, in turn, urged them to exert more effort to counter EI (via food/beverage consumption) with EE (via exercise at higher intensity for longer duration). The above studies[17–19] signaled meaningful messages to people desiring to lose weight. However, the findings were limited to overweight or obese adults. Limited research evidence is available concerning the utility of the SWA among the youth population.

Coupling SWA with a user-friendly diet journal makes a comprehensive package to track EB (EE−EI).[16,20] These two tools were found to be conveniently and accurately estimating EE and EI in adults.[20] Given the positive outcomes in adults, it was expected that these two tools could be used for EB promotion among youth. Through intensive literature review, we were able to locate one study that incorporated the SWA and diet journal package in adolescents ($N = 90$). Specifically, in this study, the adolescent participants were instructed to utilize the two tools for 7 consecutive days, and they demonstrated a positive motivation to track their EE and EI, although the EB knowledge increase, as a result of tracking EB, was not significantly higher than that in the control group.[16] Nevertheless, the above evaluation result was based on the quantitative methodology that employed a standardized written test. The written knowledge test used in this previous study might have not fully captured the participants' understanding of the EB knowledge. A mixed methodology that examines the process of using the two tools would complement and/or verify the previously reported evaluation results. Therefore, the purpose of the present study was to examine adolescents' experience and perception of using the SWA and diet journal over the course of 7 consecutive days. Specifically, we attempted to identify (1) adolescents' ability to track energy using the SWA and diet journal, and (2) the educational and motivational meanings of using the two tools.

Methods

Setting and participants

This study was conducted in two middle schools in a midwest state of the US. Sixth grade students in eight classes were invited to participate in the study. The lead author conducted the recruitment in physical education classes where the research purposes, procedures, potential benefits, and risks were informed following a standardized protocol. The sample consisted of 22 male and 23 female 6th grade students (Caucasian: $n = 34$, 76%; age: 11.7 $\pm$ 1.8 years) who voluntarily consented to participate in the study. The average Body Mass Index (BMI) of the sample was (20.76 $\pm$ 3.95) ranging from 11.71 to 32.53. Eighteen (40%) participants were categorized as overweight or obese (i.e., 85th percentile BMI for 12-year old adolescent = 21.11).[21] Institutional review board of Iowa State University (IRB) and school district approvals along with parental consent were granted prior to the data collection. Sixth graders were chosen as the research population because they are at early adolescence, an age threshold when the overweight/obesity ratio starts to surge in the US.[4,22] Previous research indicates that obese youth are at a 10 times greater risk of obesity in early adulthood compared to youth with normal weight; thus, preventive intervention in this population is crucial.[23]

Variables and instruments

EE and PA

EE and PA were measured by the SWA. SWA is a noninvasive, wireless multisensor monitor worn on the triceps of the left arm using an adjustable strap. The monitor relies on five parameters (i.e., heat flux, galvanic skin response, skin temperature, near body temperature, and motion being determined by a two-axis accelerometer) to measure outcomes associated with PA. The variables generated from SWA include compliance of using SWA (i.e., % time on the body), EE (in kcal), and PA time [i.e., moderate physical activity (MPA), vigorous physical activity (VPA), and very vigorous physical activity (VVPA)]. All SWAs were set up to record data in the 60 seconds epoch. Data for these variables were processed by the SenseWear Professional 8.1 software (BodyMedia). Previous research has shown that SWA has outstanding validity in assessing youth free-living EE and PA.[24]

Energy intake

EI was measured by the diet journal utilized in a previous study.[20] The journal is a portable 11 cm $\times$ 14 cm logging book that prompts users to document time of entry, type, amount, unit, brand, and preparation method of each food/beverage entry. If difficulties were encountered in logging the journal,

participants were instructed to: (1) read food/beverage labels, when available; (2) refer to the examples provided in the journal; and (3) seek help from adults or more knowledgeable people. A trained data analyst entered the data from each diet journal into Nutritionist Pro (Axxya Systems, Stafford, TX, USA), a reliable computerized software for diet analysis (EI measured in kcal).[20]

Perception of the experiences

The participants' perception of using the SWA and the diet journal was assessed by individual interviews. The interviews were conducted in a semistructured format. The questions asked participants about the compliance of using the SWA and the diet journal, positive and negative experiences, knowledge learned, and intention for future behavior. The interview guide is shown in the Appendix. Interviews lasted for 5–10 minutes for each participant. Conversations were recorded and transcribed.

Data collection

Each participant utilized a SWA and diet journal for 7 consecutive days. First, they were gathered in a teacher-designated school space (e.g., fitness room). Second, each participant was provided with an individually configured SWA and a new portable diet journal. Instructions on how to use these two tools were delivered following a standardized protocol. Third, to increase participants' familiarity with the tools and reduce the reactivity bias, a 1-day trial of the tools prior to the study was arranged.[25,26] Fourth, the participants utilized the two tools to track energy in the next 7 days. In the middle of the week, they were provided with informational feedback regarding their current total EE, moderate-to-vigorous PA (MVPA) time, number of steps, status of using the diet journal, as well as suggestions for using the diet journal in the following days. Lastly, the SWAs and the completed diet journals were collected at the completion of the study. Interviews were then conducted with each participant in the teachers' offices.

Data reduction and analysis

The data derived from the SWA and the diet journal were reduced by a trained research assistant. To process the SWA data, all monitors were individually connected to a desktop computer where data were downloaded to its hard drive. The SWA data were downloaded on a desktop computer and the key variables (daily % of wearing time, PA time, and EE level) for each of the 7 days were extracted using the Sensewear 8.1 platform (BodyMedia) and exported to Microsoft Excel 2013 for analysis. To process and reduce the diet journal data, the trained analyst entered the daily diet records (i.e., food name, preparation method, unit, and amount) completed by each participant into the Nutritionist Pro software (Axxya Systems). The daily amount of EI along with other dietary details (e.g., amount of nutrients) was generated by referencing and accessing the latest national dietary database that the software was connected to by default. The data were then entered in the same Excel spreadsheet as SWA data for analysis. Separate columns were further created to enter the compliance data (i.e., number of days the journal was being logged). The data reduction process proved to be rather time-consuming (> 120 hours for the diet journal data), and the analyst was compensated for the contributed work.

Data analysis involved both quantitative and qualitative methods. For the quantitative method, analyses summarized the frequency of activity and diet logging and descriptive daily patterns of these variables (e.g., PA time, EE, and EI). Figures were created in Excel to illustrate these results. For the qualitative method, interview transcripts were analyzed by the lead author using NVivo 9 (QSR International, Cambridge, MA, USA). The analysis of interview data were operated using two sequential methods: descriptive and interpretive. For the descriptive method, frequency and percentage of the salient behaviors and perceptions were tallied to verify and/or complement quantitative data. Then, the grounded theory method was utilized for the interpretive method. Corbin and Strauss' instructions[27] were closely followed to generate categories and their meshed relationship, depicting the adolescents' experience and perception of tracking EB. First, the lead author, as the analyst, read the transcripts line-by-line while listening to the recorded conversations. This step proved to be essential for the analyst to make sense of the data and confirm data accuracy. Second, as the analyst repeatedly read the transcripts, he started open-coding by assigning summative codes to keywords, sentences, and paragraphs. Third, open codes were gathered, organized, and then reduced to emerge categories. Each category was defined and described by properties and dimensions. Fourth, a central category was identified and relationships between the central category and the remaining categories were mapped out and theorized using a conceptual model (i.e., axial coding[27]).

Results

Compliance with using the SWA

The participants wore the SWA most of the (85 ± 5%) week. As displayed in Fig. 1, the daily compliance pattern

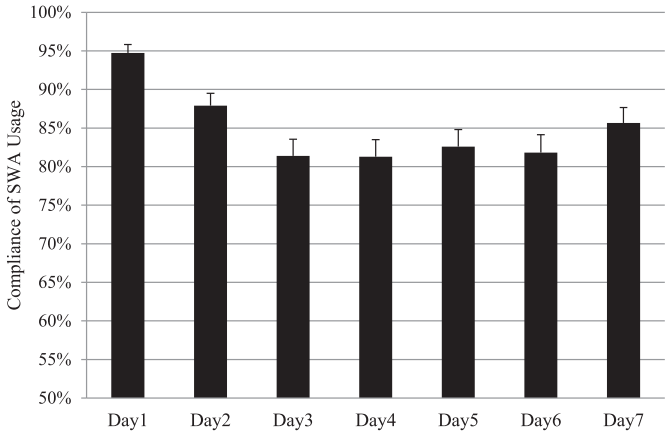

Fig. 1. Compliance/persistence of using the SenseWear Armband (SWA).

presents a tilted "V" shape where Day 1, Day 2, and Day 7 had higher compliance (i.e., ranging from 88% to 95%) than Days 3–6 (i.e., ranging from 81% to 83%). The results were verifiable by interview data. Specifically, the majority ($n = 41$, 91%) of the adolescents perceived SWA as "cool", "fun", easy-to-use, and informative. Despite the overall liking trend, some ($n = 17$, 38%) reported negative experiences. These experiences included that (1) SWA beeped unexpectedly ($n = 7$), (2) arm felt itchy ($n = 5$), and (3) red marks left on the skin ($n = 5$). Notably, as time progressed, discomfort or concerns mitigated. The following quote was from a female participant who became accustomed to wearing SWA:

> "There were some parts I was worried, like, if it's going to fall off when I was sleeping but it didn't. It wasn't uncomfortable but you were aware it was there. So, it wasn't the most comfortable thing to be wearing. After I stopped wearing it for some time, [I wondered] "is it still there?" and then [remembered] "wait, I already gave it back."

Compliance with using the diet journal

The participants utilized the diet journal for > 5 days (5.58 ± 2.15 days). Twenty two (49%) participants used it for all 7 days but 10 (22%) participants used it for only ≤ 1 day. Further, some participants logged their entries in more detail than others. Interview data showed that many participants experienced one or several of the following behavioral issues: (1) forgot to carry the journal with them, (2) was unsure about the brand, serving size, and amount of the foods, and (3) stopped logging the journal because it was time-consuming. For example, a participant who tried hard to write the journal found it too difficult to sustain behaviorally, and she explained:

> "It was hard to keep up sometimes …. I forgot it when I went to a birthday party …. I forgot to write it down but then I remembered what I needed to do. ... [If] you ate an orange or something, it's hard to decide how big or small it was. You just say one and you wouldn't know what else to say. But if you had a cup of cereal, like one cup, three or four cups of cereal, then it's easy."

Energy flux over the week

Fig. 2 shows the PA level over the monitoring week. The participant performed MVPA (sum of MPA, VPA, and VVPA time) for over 3.5 hours per day (218.06 ± 26.50 minutes). Day 1 showed the lowest MVPA level while Day 3 showed the highest MVPA level (Fig. 2).

Fig. 3 shows the energy flux pattern being represented by daily average EE and EI for the week. EE was higher than EI on 4 of the 7 days (i.e., Day 2, Day 3, Day 5, and Day 7). For the entire week, total EE was considerably higher than total EI with a discrepancy of 4582 ± 7328 kcals, suggesting a state of negative EB (i.e., −655 kcals per day).

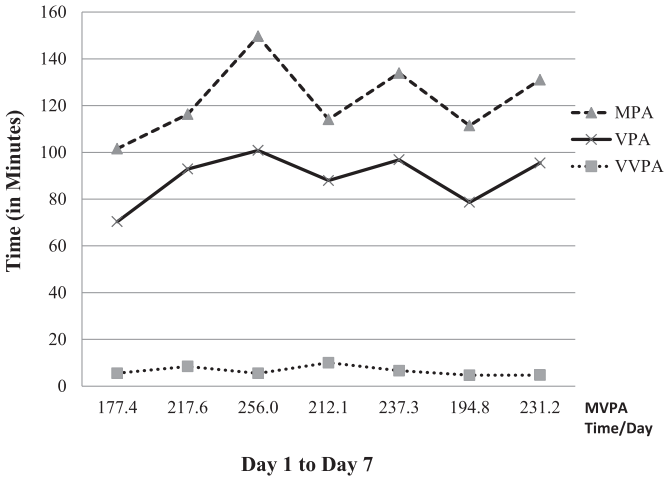

Fig. 2. Minutes spent in different intensities of PA over the 7 days. MPA = moderate physical activity; PA = physical activity; VPA = vigorous physical activity; VVPA = very vigorous physical activity.

Learning from the experience of tracking EB

The participants showed varied levels of understanding about the purpose of using the SWA and diet journal. Approximately half of the participants ($n = 27$, 47%) were able to clearly state the relevance of both EE and EI for weight management. They enjoyed using the two tools and were able to point out the importance of maintaining a healthy weight. For example, one female said:

> "[I learned] about how much you ate, how many calories you ate, how much exercise you did, and a lot about [being] self-conscious of what you are eating."

However, a large number of participants ($n = 20$, 44%) did not perceive EB as a combination of EE and EI. Being asked about the purpose of using the two tools, they mentioned either to track EE (e.g., "so you can see how many calories you burned") or EI (e.g., "to see what you are eating"); that is, EE

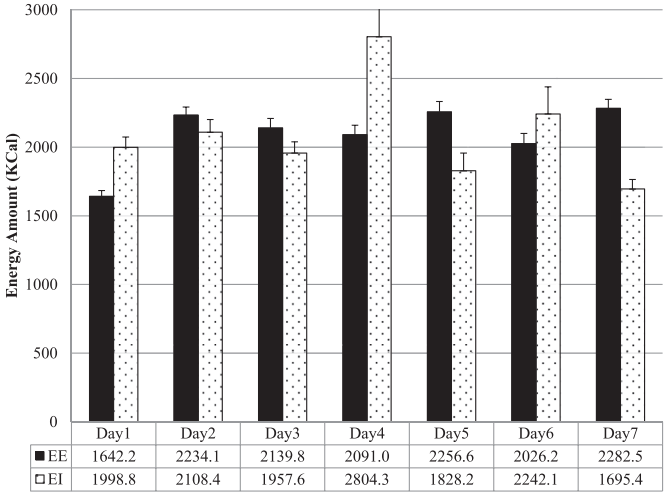

Fig. 3. Comparisons of energy expenditure (EE) and energy intake (EI) across the 7 days.

and EI were thought of separately. In addition, several participants ($n = 4$, 9%) reported not learning anything or "I don't know", indicating inadequate knowledge about the PA-diet relation and its implications for weight management.

Intention for future behavior

When being asked about their plans to track their EB in the future, 17 (38%) participants stated positive intention, 14 (31%) participants stated negative intention, and 14 (31%) participants stated uncertain intention. Of the 17 participants with positive intention, some had more specific plans than others. Below shows the interview transcript with a participant having a specific plan:

> Interviewer (I): "Do you have any plans to track and control your calories?"
>
> Participant (P): "I actually thought about making a food journal and use that to see how many calories I was eating."
>
> I: "How about monitoring your exercising?"
>
> P: "I was thinking about timing everyday how long I can keep active."

The concept of monitoring EB was also viewed as more of remedial action for older and unhealthy individuals than as a preventive behavior for youth. Below are some specific responses from several participants when being asked of their intention:

> "When I am older, like when I am unfit, I probably am going to do that."
>
> "It will be easier to do it when you are older." "He (the participant's father) keeps what he eats and how many calories. I might do that. But he is doing that because he thinks he is fat."

Pathway(s) to learn EB

Fig. 4 depicts the pathway(s) to learn knowledge and behavior related to EB. The interpretive analysis of interview data generated four major categories: experiences in the study, compliance of using SWA and diet journal, learning about EB, and intention for future behavior. Each category had at least one property and two dimensions. Specifically, the properties (and dimensions) were quality of the experiences (positive, neutral, and negative), level of compliance (high, medium, and low), level of learning (higher and lower learning), and level of intention (high and low/no). Learning about EB was identified as the central category. Salient data supported three pathways to learn EB. Of three, positive experience in the week-long experience was associated with a higher compliance level; positive experience and high compliance level jointly facilitated adolescents' learning about EB knowledge and behavior, which in turn led to stronger intention to track energy in the future.

Discussion

This study examined adolescents' experience and perception of tracking activity, diet, and energy flux over 1 week. The majority of adolescents were able to use and appreciate the utility of the SWA and diet journal for self-monitoring. The incorporation of these components within a physical education program also demonstrates the utility and feasibility for education on EB.

The use of the SWA to track activity and EE was well received by the adolescents. Compliance in monitoring was good and there was some evidence that wearing the monitor may have even prompted increases in PA behavior. The adolescents' daily MVPA was higher than that reported in previous research (mean MVPA on weekdays: 124 minutes and 96 minutes for 11 year olds and 12 year olds, respectively; mean MVPA on weekend days: 120 minutes and 84 minutes for 11 year olds and 12 year olds, respectively).[28] While it cannot be confirmed, the high compliance of using SWA may be attributable to motivation factors such as situational interest. Previous research showed that higher situational interest originated from novel, challenging, enjoyable, attention-demanding, and exploratory experiences led to positive influences on engagement and achievement.[16,29,30] In this study, SWA was introduced and used in a way that was situationally interesting.[16] The technology was perceived as "cool" and sufficiently challenging to inspire enjoyment, and to demand attentive effort as well as exploration. However, like other modern technology used for PA promotion (e.g., the Dance Dance Revolution),[31] situational interest about the SWA (as well as the diet journal) tends to level off with prolonged exposure. This is evidenced by the declining compliance at the end of the week.

The diet journal enabled the adolescents to document their EI. However, less than half of the participants utilized the diet journal for all 7 days. The relatively low compliance might be attributed to the extra effort required to recall, discern, and document EI-related information, which might have compromised the adolescents' persistence and compliance in using the diet journal. Verified by interview data, tracking EI via the diet journal was perceived as difficult, challenging, or sometimes burdensome, suggesting the need to revise the logging format and to alleviate the concerns. In addition, the lower compliance of using the diet journal led to inaccurate reporting of EI. Archer et al[32] examined the validity of a national survey for EI among men ($n = 28{,}993$) and women (34,369) aged 20–74 years. The study showed that both men (281 Kcals/day) and women (365 Kcals/day) under-reported their EI at the survey.[32] However, similar evidence in youth is not available. As illustrated in Fig. 3, the present study revealed that the EE exceeded EI in 4 of the 7 days and the EE total was considerably greater than the EI total in the week. This result may imply that the adolescents might have under-reported their EI. However, this could not be verified as the inconsistent EI

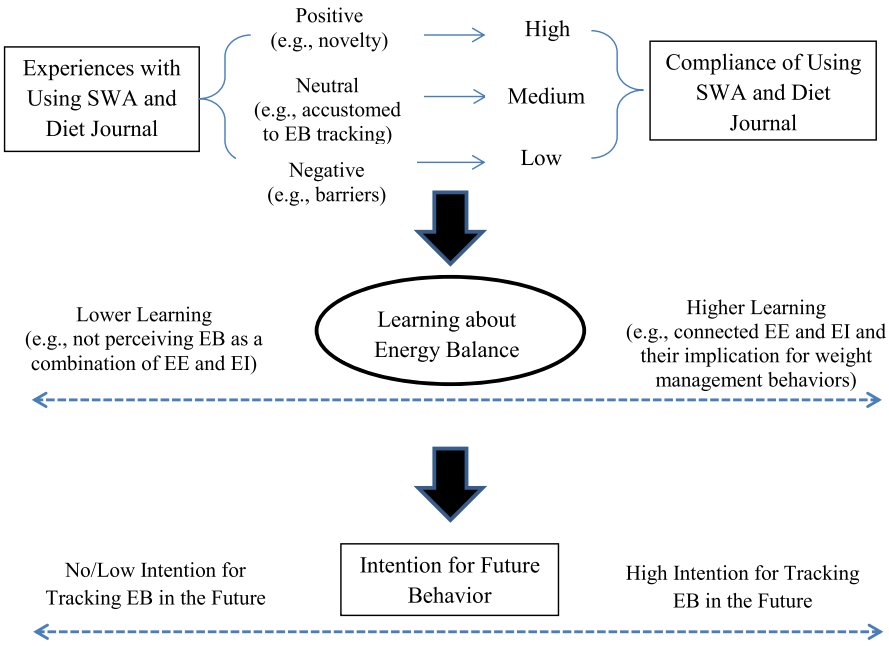

Fig. 4. The pathway(s) to learn about EB. EB = energy balance; EE = energy expenditure; EI = energy intake; SWA = SenseWear armband.

results were largely influenced by the fact that the diet journal was under-used. The under-usage of the diet journal could be related to the age characteristic of participants. Previous research documented that adult users' daily EB varied on a day-to-day basis but it averaged out at the end of the week.[20] Compared to adults, adolescent users have a shorter attention span and are less rational. Consistently logging nutritional information is an uncommon practice and requires strong perseverance and self-regulation. Future research and practice should provide more amenable experiences associated with tracking EI. For example, using validated smart phone applications or online software may be more inviting and, thus, more accurate.

The simultaneous tracking of EE and EI provides an opportunity to teach youth about the principles of EB. Many adolescents took advantage of the opportunity to learn about their daily EE and EI patterns. The qualitative findings demonstrate that this helped the adolescents learn that weight fluctuation is, by and large, regulated by both EE and EI. The positive experience and perception facilitated adolescents' learning outcome, which in turn influenced their intention to track and control calories in the future. As shown in Fig. 4, adolescents with positive experiences, high compliance level, and high understanding of EB demonstrated a strong intention and potentially more positive behavior to track energy. It was also found in the study that some adolescents gained a partial or intuitive understanding of EB as well as its implication for weight management. This conception is consistent with the conclusion of Chen et al[16] that EB knowledge is amenable to change.[16] The present study built on this past study by incorporating process data to examine factors that may influence changes in EB knowledge. The results showed that adolescents who consistently utilized the SWA and diet journal had more positive effects than students that did not consistently use the tools. Nevertheless, this finding needs to be verified by comparing the results with a control group.

Previous research found that a substantial proportion of adolescents lack knowledge about EB,[10,12] especially the higher-order, relational understanding of the knowledge.[11,12] The above findings highlight the need for purposeful education using innovative curricular and/or technological interventions to educate youth about energy-balanced living. In this regard, the pathway(s) to learn EB (Fig. 4) serves as a comprehensive guide for future research on the topic.

The findings of this study should be interpreted with several limitations. First, constrained by the policy of the university IRB, the participants were recruited on the voluntary basis. It is likely that these participants enrolled in the study with strong motivation. Thus, the results might have been skewed to some extent because of this nature. Furthermore, the sample in the present study was primarily constituted by Caucasian participants (76%). Thus, the findings are only generalizable to populations of similar demographic characteristics. Second, inconsistent use of the diet journal might have moderated the day-by-day comparison of energy flux (i.e., EE and EI). While the compliance with using the SWA was relatively high for all participants, the lower compliance with using the diet journal has led to under-representation of data points from all participants in the sample, causing skewed results. Third, the SWA and diet journal data were tracked and analyzed sequentially from Day 1 to Day 7 to capture the participants' compliance with using the tools. The present study, however, did not differentiate these data between weekend and week days; while, in reality, PA and dietary behaviors in youth may vary between those days. Last but not least, the interview data were independently coded by the lead author only. Although standard procedures[27] for

coding qualitative data were followed and the analyst had great familiarity with the data, having another qualified coder analyze part of the data to reach a high level of inter-coder reliability would enhance the data trustworthiness.

Conflicts of interest

The authors declare no conflicts of interest.

Funding/support

This work was supported by the College of Human Sciences Intramural Collaborative Seed Grant Program of Iowa State University.

Appendix. Supplementary file

The supplementary file related to this article can be found at http://dx.doi.org/10.1016/j.jesf.2015.01.001.

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