How healthy is my design? How to measure the psychological and physical benefits of engineering?

¿Cuán saludable es mi diseño? ¿ Cómo medir los beneficios psicológicos y físicos de la ingeniería?

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Abstract

Obesity and mental health are increasingly becoming issues for both children and adults in many countries. This paper investigates the potential for engineering and architecture to play a role in increasing people's well-being by designing healthier buildings and infrastructure. We explore the issue in relation to children's play equipment, specifically designing a Play Value Metric (PVM) that allows for a rating of both the psychological and physical health effects of their structure. The physical and mental values used in the medical assessments of a design are drawn from an array of tried and tested methods including qualitative, quantitative, observation or survey based data. The paper concludes with an example of how a Play Value Metric can be created for play equipment and how this might offer new market direction for companies wishing to promotes the designs as being beneficial to health.

Keywords: Play, Health Metrics, Psychometrics, Healthy Design

Resumen

La obesidad y la salud mental son cada vez más problema para niños y adultos en muchos países. Este trabajo investiga el potencial de la ingeniería y arquitectura para jugar un papel en el aumento del bienestar de la población mediante el diseño de infraestructura y edificios más saludables. Exploramos el tema en relación con el equipo de juegos para niños, específicamente diseñando un juego valor métrico (PVM) que permite una clasificación tanto de los efectos en la salud psicológica y física de su estructura. Los valores físicos y mentales usados en la evaluación médica de un diseño provienen de una variedad de métodos de probada eficacia, incluida la observación cualitativa, cuantitativa o base de datos de la encuesta. El trabajo concluye con un ejemplo de cómo puede crearse una métrica de valor juego para el equipo de juego y cómo esto podría ofrecer una nueva dirección de mercado para las empresas que deseen promover que los diseños sean beneficiosos para la salud.

Palabras clave: juego, la métrica de la salud, Psicometría, diseño saludable

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Introduction

The impact on society of increased inactivity in terms of childhood obesity (Biddle, Gorely, & Stensel, 2004) diabetes (Young, Dean, Flett, & Wood-Steiman, 2000) hypertension, osteoarthritis, and cancers (Must et al., 1999) is significant. The economic cost of disease is increasing and increasing pressure is being placed on health services.

This paper investigates the potential for improving design of play equipment to improve the outcomes of children's activity for health. We present ways in which the mental and physical health effect of children's play equipment can be measured and benchmarked for comparison for other products, which we have termed the Play Value Metric (PVM). Whilst efforts have been made in environmental psychology to assess the design of more psychologically beneficial environments in areas such as office spaces (Dravigne, Waliczek, Lineberger, & Zajicek, 2008; Larsen, Adams, Deal, Kweon & Tyler, 1998) little has been done to measure the psychological or physical benefits of the architecture itself.

One may quite rightly ask why should an architect or product designer wish to measure the medical benefits their product can offer? The authors feels that this question needs to be addressed for several reasons, firstly whilst there are many target groups for whom health inspired designed principles might be useful, take sedentary office workers for example, some studies show that inactivity at work can have as severe health effects as smoking (Buckley et al., 2015; Maguire, 2016).

The authors feel that the issue of child morbidity is also a pressing concern, especially in an era when increasing child obesity (Biddle et al., 2004) diabetes (Young et al., 2000) hypertension, osteoarthritis, and cancers (Must et al., 1999) are becoming more prevalent in children due to inactivity. Never has there been a greater need for architecture to promote health.

Regular physical activity for children improves psychological and physical health (Harsha 1995; Pellegrini & Smith, 1998; Walsh et al., 2006), although the intersection of physical activity and play is a complex social process that involves stakeholders such as parents/cares, teachers, playground supervisors, school governors, local authorities and the children themselves. As well as a comprehension of the relative levels of mental and physical ability of the children involved. Hence the interaction of play and physical activity is inherently associated with risk and exclusion. An attempt to create a model of this multi-stakeholder interaction of play can be found in King (2008) who used the tripartite biopsychosocial model first developed by Engel (1977), which can be seen in Figure 1.

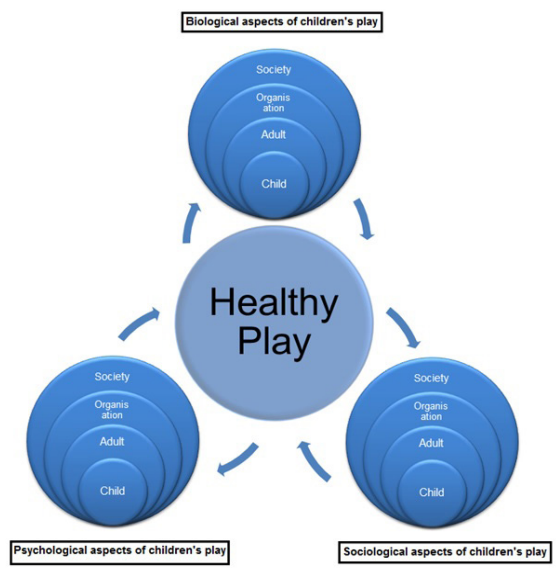

Figure 1. The Biopsychosocial model of play adapted from King (2008)

This model essentially highlights the complexity faced when attempting to socially engineer health changes in a group of people. In designing play equipment for the promotion of health, one cannot realistically expect it to be effective without a consideration of the other psychological and social factors. Given the complexity of the issue we feel that it is important that the design of equipment does not occur in a vacuum if it is to succeed. Consequently, issues of a biological, psychological and social nature will be discussed in the following sections. In addition, we also recognised that although this paper is about children' play equipment there is potential for the methodology to be applied to many other areas of design or architecture.

Why and How to measure the Health Effects of Play Equipment?

In many developed countries children in schools do not meet the recommended levels of daily physical activity (Biddle et al., 2004; Welsman & Armstrong, 1997). The level typically set as a threshold is one hour of moderate to intensive physical activity each day (Cardon, Verstraete, De Clercq, & Bourdeaudhuij, 2004; Dyment, Bell, & Lucas, 2009; Nader, 2003). Hence in this regard there is a gap in the market from a policy perspective to design play equipment for the promotion of physical and mental health.

The activity levels of children in studies is not however dependent solely on their own agency (Bell, Phoenix, Lovell, & Wheeler, 2014). For example McKenzie et al. (1997) demonstrated that by teachers and playground assistants prompting the children to use equipment, higher levels of physical activity were observed. There is some debate that increasing physical activities levels at school only leads to a decrease in levels at home as the child compensated for the additional effort (Donnelly et al., 1996), with others suggesting that this is not the case (D. Dale, Corbin, & Dale, 2000).

The level of intensity of the play will affect the health benefits felt by the child. For example only vigorous types of play will be affective in addressing cardiorespiratory issues that might arise in children (Payne & Morrow 1993), whereas other less active forms of play may be better at reducing other conditions. For example is it slowly being accepted (for better or worse) that moderate levels of activity are sufficient to tackle basic issues of obesity (Frank, Andresen, & Schmid, 2004). This process also has to take into account the variation in physical abilities of children so as not to be exclusionary (Barbour, 1999). Building on this it is also important to note the 7 facets of what Williams (1992, 1994) termed the *Physical Education Hall of shame.*

Not all of these categories will be relevant at all times but it does serve as a useful basis upon which to introduce social context and limitations into the design strategy. In addition, Williams' work highlights the need to integrate and mitigate issues of risk and exclusion into play without reducing the level of activity undertaken. In the following section we will consider some of the other issues that need to be accounted for in the wider contexts when designing play equipment for children.

Structure and play

It has been suggested that top-down attempts at structuring play are less successful than those which are non-structured or where the encouragement to play is subtle (Pate, Baranowski, Dowda, & Trost, 1996). Examples of this subtle approach are things like the use of multicolour playground markings (Stratton, 2000; Stratton & Mullan, 2005), or the use of Exergaming (Daley, 2009). Indeed, Moore & Wong (1997) remarked on the need to allow children to "*expand their play repertoire*" without the perceived interference from adults. Issues around how narrative and nature can promote play are covered in depth by Sobel (2002). This topic was is touched on by Dyment et al. (2009, p. 270) when she stated that:

> "by adding colour, open-ended play opportunities and external stimuli for imaginative play, physical activity in children within the school playground may be improved".

It would seem that a light touch approach is best for encouraging physical activity, and also this can be facilitated through the use of narrative or imaginative play scenarios. However, play is also connected to memory as much as it is to the structure of the equipment itself.

Play and Memory

In an effort to consider multiple points of view one must consider how a design would appeal to parents or other adults, and in this regard it is useful to consider the role of memory. It is no surprise that adults retain childhood memories and also that these are used to construct what parents consider is best for their children (Sebba, 1991) e.g. policy makers when choosing play related equipment for children will in part be drawing on their own childhood experiences, as well as other factors such as economics, research etc. Equally children also use memory to reconstruct play sequences, usually based on a narrative. Hence the design of play equipment could fit well into the narrative structures of memory such as those outlined by the works of David Sobel (Sobel, 1990, 2002) or others such as Fantasy play, Imaginative play, or Rough and Tumble play that are characterised by Hughes (2002) would seem advisable starting points.

Whilst issues of memory, narrative, structure and agency in design are certainly important to consider, it is the measurement of the somatic and psychometric scores that allows a designer to see how biologically and psychologically effective their creations are. The measurement of the health effects of play equipment is needed is because it allows you to evaluate the design from the perspective of its user (Von Hippel, Ogawa, & De Jong, 2011) and also open up new market opportunities based on hard data not just aesthetics. The next question that naturally follows this is how to apply the construction of values to play? Potential measurements of both the physical and psychological effects of play are set out in the following section on the Play Value Metric.

Play Value Metric Model

Physical values

LaPorte, Montoye, and Caspersen (1985) highlighted 30 different methods that have been used to assess physical activity in epidemiological research, stating that "No single instrument fulfils the criteria of being valid, reliable, and practical while not affecting behaviour" (ibid, p. 131). Hence it would seem that there has to be a carefully constructed mix and match approach in measuring the physical values of play. LaPorte et al. (1985) suggest that these 30 different methods fit into 7 different categories (with associated sub-categories) which can be seen below in figure 2:

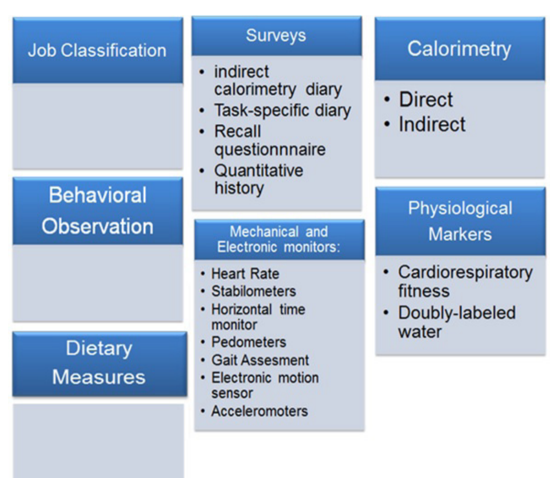

Figure2. Common methods that have been used to assess physical activity in epidemiological research

Not all of the categories will be relevant for the analysis of play for example: dietary measures are not applicable for assessing the value of play on particular equipment, neither are the categories of job classification or the surveys of dietary activities. However, if one were to evaluate a design with a different function these additional categories may be of use. Equally the water technique which involves in the ingestion of isotope containing water may not be suitable for children; as such measures have to be tailored to the specific users in mind. This leaves the following measurements that could be applied to value the physical impact of play:

1. **Calorimetry**

    1.1 Indirect

2. **Mechanical and Electric monitors**

    - 2.1 Heart Rate
    - 2.2 Pedometers
    - 2.3 Accelerometers

3. **Behavioural Observations**

Calorimetry

The first of these measures is calorimetry, specifically indirect calorimetry as the direct form requires the use of special chambers that would not be possible in the play environment (ibid, p. 132). Indirect calorimetry measures the consumption of oxygen whilst undertaking an activity i.e. the number of calories spent. This technique is extremely accurate with only a 2-3% error in the measurements (ibid) but it has the significant downside that the participant must wear a facemask to capture the rate of oxygen consumption. This severally alters how a child would interact with their play environment, as well as adding extra weight it could potentially bias the psychological measures of a child's experience. Due to this as a method it would only have a limited application to very specific circumstances.

Mechanical and Electric monitors

Heart Rate

This is just as it sounds a device that can measure intensity and duration of the heartbeat, heart rate is used as it has a direct connection to energy expenditure (Eston, Rowlands, & Ingledew, 1997). The rate of the heartbeat will be proportional to the intake of oxygen in a person. The issue with the measurement comes from the fact that there are both physiological and psychological factors that can alter heart rate such as muscle mass, environmental temperature, level of physical fitness, emotional stress etc. Hence the method would have to be applied in a clinical trails methodology with pre and post monitoring of the of cardio activity to show the differences. Also it could benefit from observational methods to assess if there are psychological factors occurring that might skew the data (such as stress) in the child. Probably the most up to date piece of cardio equipment is heart rate telemetry, which was used by Stratton (2000) as a mechanism to measure heart rate.

Pedometer

This form of motion sensor offers a way to measure physical activity that is not based on energy expenditure. It is one of the most common non-calorific measurements of physical activity. It measures the number of steps taken and so the distance a person has covered either walking or running over a given period of time. As pieces of equipment they are relatively accurate (Bassett et al., 1996) but the information they provide is not particularly clinical. The step as a unit is clearly a real event but it is hard the make the causal link that more steps means a more highly valued play scenario without supplementary data.

Accelerometers

These devices in a play context will be used to record movement over time in a given terrain which can then be turned into a map showing where the child went, at what time and at what speed. These devices can also measure temperature over the same time interval as a proxy or physical activity, for an example of their application in an health context see Bell, Phoenix, Lovell, and Wheeler (2015). In this manner accelerometers are not dissimilar to pedometers except the unit of output is not steps but meters per second squared (m/s^2) known as a count, it is perhaps harder to conceptualise and draw inferences from. The accelerometer also remains significantly more expensive than the pedometer to purchase (Oliver, Schofield, Kolt, & Schluter, 2007). Since the work by LaPorte et al. (1985) on identifying ways to measure physical activity was in 1985, one might have expected the technology to have advanced somewhat. However, most studies seem still to use accelerometers for measuring the physical activity of children whilst at play (Bundy et al., 2009; Trost, McIver, & Pate, 2005). The quality of the electronics and the way it interfaces with other aftermarket software has no doubt improved. But the number of tools that can be utilised seems to be relatively set, the only exception being the software available to model motor skills:

Motor Skills

In addition to the list given by LaPorte et al. (1985) the assessment of motor skills in children playing is also possible. This is either done by observation (see below) or by kinematic video software that can be used to evaluate the motor skills of children in a play situation. Hence the play is video recorded either by placing cameras on the child or by other means and using a software packages to code how particular movements influence the uptake of motor skills.

Critique

The equipment and techniques mentioned so far are concerned primarily with short term observations. But if a set of children was observed over time, then the changes in biological factors like body fat level, blood lipid level, cholesterol etc. might serve as a better way to evaluate the health impacts on a child. However, such a study may prove difficult especially if all play equipment was to be rated on long term based studies. Use of equipment has one inherent error that if all versions of an item are not calibrated the same the readings will be incommensurate.

Behavioural Observations (physical)

Observational techniques utilise many different medias, either visually by an observer, photographically or by making videos of the play for the purpose of analysis, for an example see European Centre for Environment and Human Health (2015), Waters (2014). As stated there are psychological determinants that will affect the data collected in either calorific or cardio respiratory related observations. The quantitative measures by themselves make it hard to conclusively establish a link between physical activity and a value for play. This makes combining an observational approach essential for rigorous play based research. Measuring motor skills by observation essentially revolves around rating the ability of a child to complete a set number of specific tasks. For example, a crib sheet taken from Ericsson (2008) showing how to rate different activities can be seen in Figure 3. This is one of the few direct uses of observational techniques, in most cases of assessing the value of physical activity observational material is used as a supplement to validate the quantitative measurements of the pedometers or accelerometers (Baranowski et al., 1984).

The MUGI Observation checklist is intended for the use of school nurses, physical education teachers, trained sports coaches/teachers, and special needs teachers, under supervision of a trained physical education teacher.

Date:........................... Observer:...

Class:................. Group:.................. No. of Girls:........... No. of Boys:............

Pupil's physical education teacher:..

MUGI Task	Minor Difficulty	Major Difficulty
1.Throw and catch a large ball 5 consecutive times		
2.Bounce large ball 5 consecutive times		
3. Skip in a diagonal pattern forward 15 meters		
4. Hop on one leg for 7 meters		
5. Stand on one leg for 10 seconds		
6. Imitate body movement and positions in the game 'Simon says'		
7. Obstacle course		

Figure 3. Example of motor skill monitoring form, adapted from Ericsson (2008)

One of the limitations of observational methods is the amount of man power it requires. The technique cannot be used on a large population unless there are sufficient numbers of observers. This should not be an issue however for evaluating play equipment on an individual basis. There is a plethora of literature on the role that observers play in a research setting and the potential biases that they can introduce (Grimes & Schulz, 2002). These issues are well known and can be easily accounted for.

Applying a Psychological Value to Play

An extensive list of psychological values associated with the measurement of mental health and well-being exist. These measurements fall broadly into two different categories (1) Mental health and well-being, and (2) Setting. The most relevant scores and systems for the application of children's play equipment were chosen, a summary of which are given in the following section.

Mental Health and well-being

Strength and difficulties questionnaire SDQ

The strength and difficulties questionnaire is composed of 25 questions and is used as an initial assessment and to collect baseline data for evaluating specific interventions. It is very generic as such it will be useful in some cases but not others.

Anxiety and Depression: Revised children's anxiety and depression scale (RCADS)

The revised children's anxiety and depression scale is a scoring system used in children aged 8-18 to evaluate anxiety and depression.

Stirling Children's Well-being Scale (SCWBS)

The Stirling children's well-being scale is used to test a child's (8-15 years) emotional and psychological well-being through constructs like optimism, cheerfulness, relaxation, relationships, clear thinking and competence.

Warwick-Edinburgh Mental Well-being Scale (WEMWBS)

The Warwick Edinburgh mental well-being scale is a measure of wellbeing designed to cover positive/negative feelings, life satisfaction, vitality, optimism, resilience/autonomy, meaning, purpose and relationships in 13 year olds and up, using a 5 point Likert scale.

Well-being and Involvement - Leuven Scale

The Leuven scale deals with the extent to which school children feel at ease, act spontaneously, show vitality and self-confidence which are seen as crucial components of emotional intelligence and good mental health. It also covers involvement e.g. is a child operating to their full capabilities? Are they focused, engaged and interested in various activities etc. The scale has 5 levels of involvement with an activity: (1) Low Activity, (2) A Frequently Interrupted Activity, (3) Mainly Continuous Activity, (4) Continuous Activity with Intense Moments, and (5) Sustained Intense Activity.

Rosenberg self-esteem scale for young people

The Rosenberg self-esteem score is based on 10 items about self-attitude rated on 4 point Likert scale. This self-esteem scale is often utilised in the United Kingdom's National Health Service (NHS).

Emotional Literacy Scale (ELS) Assessment & Intervention

The emotional literacy scale is available for both 7-11 year olds and 11-16 year olds, it identifies emotional literacy and provides follow-up activities for interventions, where necessary.

Physical Activity Questionnaire For Children (PAQfC)

The physical activity question is a self-rated test designed for children (8-14 years) it poses questions such as "I feel fit and healthy, I like being active, I enjoy being outside". It is designed to look for identity shifts that drives (as well as indicates) change or maintenance of physical activity.

Setting

Perceived Restorative Components Scale for Children (PRCS-C II)

The Perceived Restorative Components Scale is a 15-item measure for children that captures each of the restorative components of Attention Restoration Theory (Kaplan, 1995).

Synthesis of Measures

The physical and psychological measures outlined so far now need to be synthesized to create a metric that will allow the evaluation of the health impacts of a particular type of design.

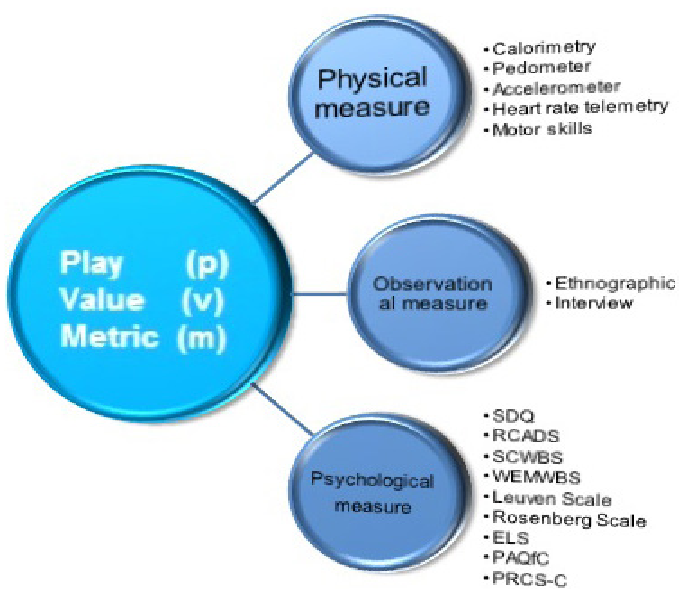

Figure 4. Inputs required to create a play value metric

To illustrate how this might work in practice Tables 1 and 2 have been constructed with weighted versions of the measurements given in the previous sections, see Figure 4. Table 1 contains the values, their units, upper and lower limits and their weightings. Table 2 uses the same construction but with dummy physical and psychological measure that can be used to create a Play Value Metric. This process can also generate a ranking for equipment based on the categories used. For example, since we have upper and lower limits to the values, a ranking system can be implemented. For the Dummy values used in Table 2 there is a maximum score of 214 and a minimum of 33. Hence in Table 3 we have created an A to F rating system in terms of the PVM score. If the physical and psychological criteria remain consistent this allows one piece of equipment to be compared to another in terms of their health value.

Table 1

Play Value Metric without variables

Category	Measure Type	Unit	Input	Lower limit	Upper Limit	Unit Value %*	Weighting* *	Output
Physical	Calorimetry	Calories burnt		0	500***		0.5	
	Pedometer	Steps		0	10000***		0.1	
	Accelerometer	M/S² (average)		0	5***		0.1	
	Heart Rate	Bpm (average)		50**	200***		0.3	
Total								
Psychological	SDQ	25 Q on 3 point Likert		25	75		0.1	
	RCADS	47 Q on 4 point scale		47	188		0.1	
	SCWBS	12 Q on a 5 point Scale		12	60		0.1	
	WEMWBS	14 Q on a 5 point scale		14	70		0.2	
	Leuven Scale	5 point scale		1	5		0.2	
	Rosenberg Scale	10 Q on a 4 point scale		10	40		0.1	
	ELS*	n/a		n/a	n/a		0.2	
Total								
Play Value Metric								

* Information only available on purchase, **These are my own hypothetical weighting, ***info to be based on expert evidence

Table 2

Play Value Metric with dummy variables

Category	Measure Type	Unit	Input	Lower limit	Upper Limit	Unit Value %*	Weighting* *	Output
Physical	Calorimetry	Calories burnt	500.00	0.00	500.00	1.00	0.50	50.00
	Pedometer	Steps	10000.00	0.00	10000.00	1.00	0.10	10.00
	Accelerometer	M/S^2 (average)	5.00	0.00	5.00	1.00	0.10	10.00
	Heart Rate	Bpm (average)	200.00	50.00	200.00	1.33	0.30	40.00
Total								**110.00**
Psychological	SDQ	25 Q on 3 point Likert	75.00	25.00	75.00	1.50	0.10	15.00
	RCADS	47 Q on 4 point scale	188.00	47.00	188.00	1.33	0.10	13.33
	SCWBS	12 Q on a 5 point Scale	60.00	12.00	60.00	1.25	0.10	12.50
	WEMWBS	14 Q on a 5 point scale	70.00	14.00	70.00	1.25	0.20	25.00
	Leuven Scale	5 point scale	5.00	1.00	5.00	1.25	0.20	25.00
	Rosenberg Scale	10 Q on a 4 point scale	40.00	10.00	40.00	1.33	0.10	13.33
	ELS*	n/a		n/a	n/a			
Total								**104.17**
Play Value Metric								**214.17**

* Information only available on purchase, **These are my own hypothetical weighting, ***info to be based on expert evidence

Table 3

PVM score ranking according to dummy values in Table 2

Play Value Metric Rank	Score
A	185-214
B	155-184
C	125-154
D	95-124
E	65- 94
F	33-64

Discussion

Previously in this paper it was we suggested that the creation of health metrics for designs are a useful tool that could help a designer or architect evaluate their products, such a metric can give you an indication of how healthy your design is. What it can't do is tell you in the first instance what the narrative or structure of the design should be before you build an object. This issue is particularly true for designing children's equipment as it may be hard to anticipate what the preference of different children will be. However, a consideration of health prior to designing an object or using health metrics on a prototype may be a valuable resource for designers. This short paper sadly is not extensive enough to cover all aspects of design but it can provide some small insight into how a health value metric could be constructed.

The Difficulty of Comparison

To come to a singular metric based on a variety of other measures possessed some significant challenges. For example, how to aggregate measures within a given system, if they are not based on the same unit of measurement? Take a pedometer reading vs an accelerometer reading. One uses the notion of step that is set in meters, but will vary according to the gait of the person under investigation – a 6 year olds' step is not the same as a 14 or 15 years olds in most cases. The accelerometer measures energy expenditure in meters per second squared (m/s^2). How can a heart rate (beats per minute) and an accelerometer (m/s^2) reading be compared or even aggregated into a score for the physical exertion? Or for psychological scales that measure the value of play?

The question posed above can be resolved by creating scales that are informed by expert advice and using existing academic literature to create a limit for each measurement and also then by weighting the degree of importance. For example, if we have an upper and a lower level for the number of calories that should be burnt over a period of time, this creates the ability to rank calorific ratings. E.g. a piece of equipment may have a lower calorific value of 150 calories burnt over a specific time period and maximum of 500 calories. The calorific values measured then can be calculated as a percentage of this and so ranked without units, making it comparable to other metrics that use the same methodology.

Conclusion

In this paper it has been demonstrated that one can combine physical and physiological measures to create a metric that allows you to value the health effects of play equipment. The specifics of these inputs of course determine how the PVM will function. In addition, as new measures of physical and mental activity are created and applied, the model would have to find a way to incorporate them. A wider issue is the difficulty in using a metric to create an industry standard that other manufacturers will adopt. There is however merit in the approach and it is certainly worth pursuing. A Play Value Metric can be a highly effective way of validating the health effects of a design or can be turned into a meaningful narrative through social marketing. We suggest that being able to scientifically evaluate a design based on robust research could add commercial value to company and also would make their products more attractive to organisations like local government, or leisure centres that wish to have designs which are proven to increase a child's health and well-being. This may also enable firms to charge an additional price premium compared to their competitors.

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