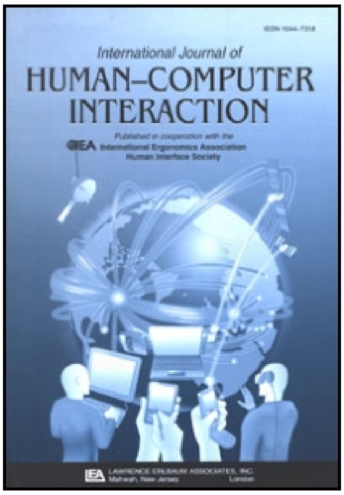

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L. Straker [a]; C. Pollock [a]; J. Piek [a]; R. Abbott [b]; R. Skoss [a]; J. Coleman [a]
[a] School of Physiotherapy, Curtin University of Technology, [b] School of Human Movement Studies, The University of Queensland,

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Active-Input Provides More Movement and Muscle Activity During Electronic Game Playing by Children

L. Straker[1], C. Pollock[1], J. Piek[1], R. Abbott[2], R. Skoss[1], and J. Coleman[1]
[1]School of Physiotherapy, Curtin University of Technology
[2]School of Human Movement Studies, The University of Queensland

The majority of children in affluent countries now play electronic games, and this has lead to concerns about the health impact of this activity. Traditional electronic games have used gamepad, keyboard, and mouse input, but newer game interfaces that require more movement are now available. However the movement and muscle activity demands of electronic games have not been described. This study compared the amount of movement and muscle activity while 20 children aged 9 to 12 years watched a DVD and played games using handheld computer, gamepad, keyboard, steering wheel and, active-input (Webcam motion analysis–Sony EyeToy®) devices. Movement of the head, sacrum, foot, shoulder, wrist, and thumb was measured along with activity in cervical erector spinae, lumbar erector spinae, rectus femoris, upper trapezius, anterior deltoid, and wrist extensor muscles. Use of the wheel resulted in some increase in upper limb movement and muscle activity, but the other traditional input devices were usually as sedentary as watching a DVD. In contrast, use of the active-input device (EyeToy) resulted in substantial movement and muscle activity in limbs and torso. These results suggest that playing traditional electronic games is indeed a sedentary activity but that new active-input technologies may be useful in encouraging more movement and muscle activity in children.

1. INTRODUCTION

Children in affluent countries have substantial exposure to Screen Based Media (SBM). This exposure includes watching TV, using computers, and playing electronic games on dedicated handheld devices (such as Nintendo Game Boy® and Sony PlayStation Portable® [PSP]) and consoles viewed on TV (such as Sony PlayStation® and Microsoft Xbox®). For example, in an Australia report (Australian Bureau of Statistics, 2003), 98% of school-age children stated they watched TV, 95%

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Correspondence should be addressed to L. Straker, School of Physiotherapy, Division of Health Sciences, Curtin University of Technology, GPO Box U1987, Perth WA 6845, Australia. E-mail: L.Straker@curtin.edu.au

reported they used computers, and 71% played electronic games. Also, children's exposure to SBM starts at an early age. We recently reported that by 5 years of age more than half of Western Australian children had used a computer (Straker, Pollock, Zubrick, & Kurinczuk, 2006]. SBM use is not only very prevalent, but daily doses are now substantial. Marshall, Gorely, and Biddle's (2006) meta-analysis of studies from affluent countries found 130 min mean daily TV viewing, 30 min computer use, and 40 min electronic game playing.

Accompanying the increase in computer and electronic game use has been a concern about possible detrimental effects on children's health and development (Roberts, Foehr, & Rideout, 2005). Research on the impact of computer use on children's physical development has focused on postures during computer use at school (Oates, Evans, & Hedge, 1998), use of laptop computers (Harris & Straker, 2000), and the impact of workstation design on posture and muscle activity (Straker, Briggs, & Greig, 2002). This research has suggested potential musculoskeletal problems associated with prolonged and constrained postures and repetitive small movements. There is also some evidence that use of computers and electronic games can improve fine motor skills but decrease gross motor skills (Yuji, 1996). Increased use of computers and electronic games has also been widely blamed for the rise in body fatness in children (Stettler, Signer, & Suter, 2004; Vandewater, Shim, & Caplovitz, 2004). One mechanism suggested for these links is that the sedentary use of computers and electronic games may displace more active leisure activities and thus result in less overall physical activity and less practice of gross motor tasks (Straker & Pollock, 2005). Current evidence supports a weak negative relationship between computer/electronic game use and physical activity (Marshall, Biddle, Gorely, & Murdey, 2004; Salmon, Timperio, Telford, Carver, & Crawford, 2005; Straker et al., 2006).

The reason for the concern about decreased physical activity is that physical activity in adulthood is an important inverse risk factor for *the* major causes of mortality and morbidity including heart disease, stroke, cancer, musculoskeletal disorders, depression, obesity, and diabetes (U.S. Department of Health and Human Services, 1996), and there is evidence to suggest that inactivity tracks from childhood into adulthood (Raitakari, Porkka, & Taimela, 1994). Furthermore, lower levels of physical activity in childhood have been linked in the short term with increased levels of obesity, poorer skeletal health (Bradney, Pearce, & Naughton, 1998; Morris, Naughton, Gibbs, Carlson, & Wark, 1997), and poorer psychosocial well-being (Boyd & Hrycaiko, 1997). In response to the growing awareness of the health benefits of physical activity and concern for possibly declining levels, specific guidelines for physical activity for children have been established (American Academy of Paediatrics Committee on Public Education, 2001; Cavill, Biddle, & Sallis, 2001; Corbin & Pangrazi, 1998; Department of Health and Aging, 2004; Sallis & Patrick, 1994; The Public Health Agency of Canada, 2002). These guidelines recommend that no more than 2 hr per day, in daylight hours, is spent on SBM for entertainment purposes. However this assumes all SBM result in low movement demands.

Precisely how sedentary children are when playing electronic games is unknown (Vandewater et al., 2004). Watching TV requires no movement and in fact has been used in studies of children by us (Abbott, Harkness, & Davies, 2002;

Ball et al., 2001) and others (Payau, Adolph, Vohra, & Butte, 2002) to obtain "resting" energy consumption values. Electronic games have traditionally used keyboard/mouse and game pad interfaces, which require very little movement. We are unable to find any detailed investigation of how much movement children produce when playing electronic games with traditional interfaces. Our research on children's use of computers for educational tasks using keyboard and mouse showed only small movements and low levels of muscle activity (Briggs, Straker, & Greig, 2004; Greig, Straker, & Briggs, 2005).

In contrast, some new domestic electronic games require "active-input" and utilize a dance mat or motion camera (Sony EyeToy®) interface and require large arm, leg, and whole body movements. Dance mats are $1m^2$ with nine pressure sensitive areas which respond to stepping; for images, see http://en.wikipedia.org/wiki/Dance_pad. The games involve stepping on the correct square in time with music. EyeToy is a virtual reality game technology that uses a video camera to capture the user's image and movement and embed this into the virtual game environment; for images, see http://en.wikipedia.org/wiki/Eyetoy. The games require the user to touch or avoid virtual objects.

Although there are no research reports on the movement of children playing these new active-input games, there is one report on whole body movement while playing traditional electronic games. Payau et al. (2002) reported hip accelerometer counts of 14 (SD = 12) and microwave motion counts of 42 (SD = 33) for children sitting and playing an unspecified (presumably traditional) Nintendo game. These values were not much greater than resting in a sitting posture (accelerometer, M = 6 (SD = 7; microwave motion, M = 23, SD = 17, respectively) and substantially less than walking (M = 940, SD = 415; M = 11,337 (SD = 75).

Recently, four studies reported energy expenditures while children played domestic electronic games. Wang and Perry (2006), Lanningham-Foster and Jensen (2006), Maddison et al, (2007), and Straker and Abbott (2007) reported heart rates and energy expenditures while children played a traditional input Sony PlayStation game to be only slightly greater than resting values. In contrast, energy expenditures while playing the new active-input electronic games were found to be greatly increased. Earlier research on active-input arcade games had also found energy expenditures were substantially increased above resting levels (Ridley & Olds, 2001; Segal & Dietz, 1991). These physiological data suggest that some electronic games can require substantial movement and muscle activity.

SBM are predicted to remain an important part of children's lives, with recent evidence showing electronic game playing exposure has doubled in the last 5 years (Roberts et al., 2005). General computer use in children has been associated with poor musculoskeletal health, but currently there is minimal information available on the movement and muscle activity of children playing traditional electronic games, and no information on these variables when children play with new active-input games. Recent studies have reported high energy demands during play with these new active-input games, which suggests involvement of major muscles. This could be important for gross motor skill development. If playing these active-input games also produces more movement, they may also have a positive effect on bone, joint, and muscle tissue development (Anderson, 2000; Faigenbaum, 2001; Rowlands, Ingledew, Powell, & Eston, 2004). Therefore the aim of this study was to compare the movement and muscle activity demands of traditional electronic games with a new active-input game.

2. METHOD

2.1. Study Design

A within-subjects design was used to test the effect of different electronic game devices on movement and muscle activity. Energy expenditure, heart rate, and minute ventilation were also examined and are reported separately (Straker & Abbott, 2007).

2.2. Participants

Twenty healthy children (12 male, 8 female) between the ages of 9 and 12 years were recruited through personal contacts and advertisements placed in community media. All children had played electronic games but were not experienced with the games provided in this study. All children were right-hand dominant. Volunteers were excluded if they had a diagnosed disorder likely to impact their movement or electronic game use. The mean (standard deviation) height and weight for male participants was 141.8 (10.9) cm and 38.0 (9.3) kg, and for female participants was 141.0 (8.7) cm and 31.6 (4.6) kg. The study was approved by the Human Research Ethics Committee of Curtin University of Technology.

2.3. Electronic Game Devices

Each child watched an animated film (*The Incredibles* from Disney/Pixar) on DVD and played games using five different game devices. A Tetris-style puzzle game of cascading blocks was played on the handheld game device (Brick Game 9999 in 1, Wellin Digital Technology Ltd, Hong Kong), similar to Game Boy (Nintendo) and PSP (Sony). A car racing game (Need for Speed Underground 2, EA Games, Redwood, CA) was played using a gamepad (Nostromo GamePad, Belkin, Compton, CA) or keyboard (Microsoft Wireless MultiMedia Keyboard 1.0A, Microsoft, Redmond, WA) or steering wheel with pedals (Momo Racing Force Feedback Wheel, Logitech, Freemont, CA) connected to a PlayStation 2 and displayed on a 30-in. LCD screen (N3000w ViewSonic, Walnut, CA). The same screen and PlayStation 2 console were also used to run the active-input, EyeToy device. The game used with the EyeToy was called Cascade (EyeToy: Kinetic, Sony Corporation, Tokyo, Japan) and required moving hands and/or feet to touch virtual targets shown on the screen. To replicate typical domestic situations, children sat on a cushion on the floor to watch the DVD and play with the handheld and gamepad devices. For the keyboard and wheel, children sat at a desk with a stool adjusted so that the desk was at their sitting elbow height, with a footstool supporting their feet. For the EyeToy, children stood about 3 m back from the screen (see Figure 1).

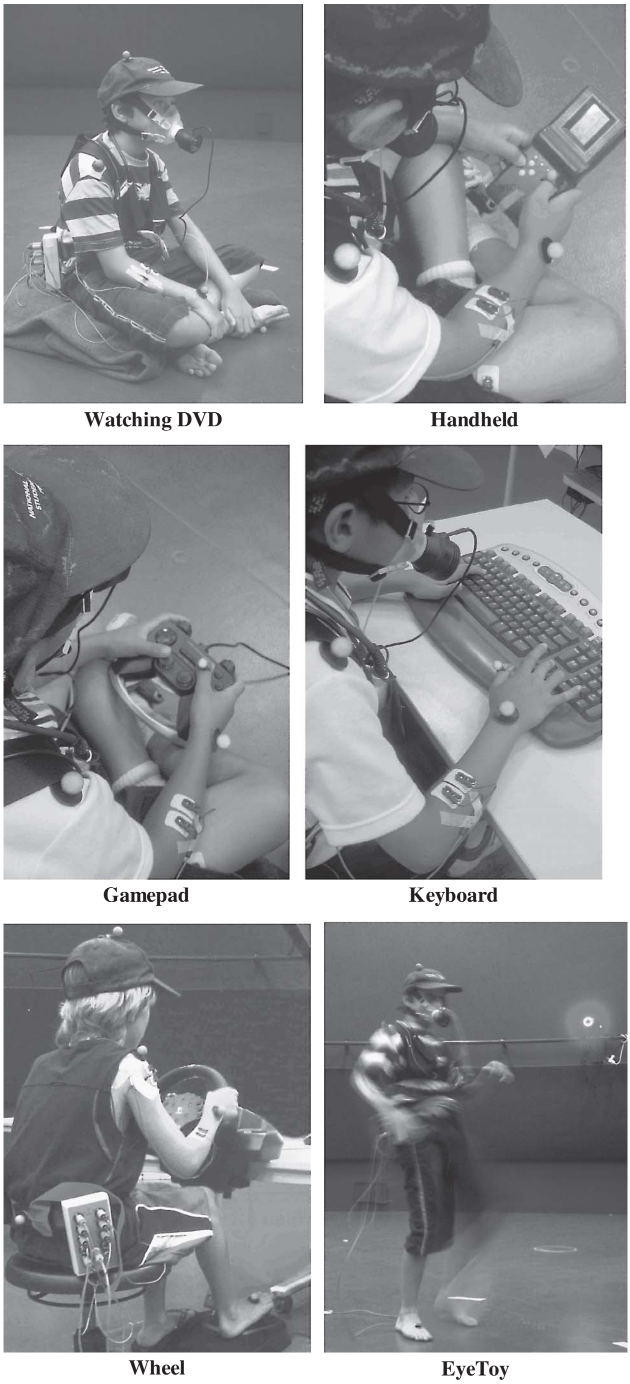

FIGURE 1 Photographs of the children interacting with the different electronic devices.

2.4. Dependent Variables

Movement. Motion data were collected using a seven camera Peak Motus 3D Optical Capture System (Peak Performance Technologies Inc., Centennial, CO) via a 32-channel A/D interface (Data Translations 3010, Data Translation Inc., Marlboro, MA). Spherical or semispherical, reflective markers were positioned on the apex of a cap worn by the participant (head), right posterior acromial shelf (shoulder), the midpoint between the right radial and ulnar styloid processes (wrist), right thumbnail (thumb), over the sacrum (sacrum) and right third metatarsal head (foot). Data were sampled at 50 Hz, then filtered and smoothed using a Butterworth filter (cutoff frequency 4 Hz). The distance travelled by each marker was calculated from the 3D coordinates of each marker, relative to ground and a proximal segment reference.

Muscle activity. In synchrony with motion data, surface myoelectric activity (sEMG) was collected from right side cervical erector spinae (CES), upper trapezius, anterior deltoid, wrist extensor bundle, lumbar erector spinae, and rectus femoris muscles. The electrode sites were prepared by shaving, lightly abrading, and cleaning with surgical spirits, before pairs of 12 mm diameter Ag-AgCl disposable surface electrodes (Uni-Patch, Wasbasha, MN) were placed 25 mm center-to-center distance. Raw sEMG signals were sampled at 1000 Hz via an eight-channel AMT-8 EMG cable telemetry system (Bortec Biomedical, Alberta, Canada) with analogue differential amplifiers (frequency response: 10–1000 Hz, common mode rejection ratio: 115 dB). Data acquisition was controlled by the Peak Motus 8 (Peak Performance Technologies Inc., Centennial, CO) software. The mean root mean square value over 60 sec was utilized for analysis. Normalisation to maximum voluntary exertion was not performed to reduce the time burden on participants. (Normalization procedures would have involved three maximal or submaximal contractions of the six muscle groups, which with instruction, practice, and rest allowances normally takes approximately 1 hr.)

2.5. Procedure

On arrival to the climate and lighting controlled motion analysis laboratory, parents and children were informed about the study and provided written consent/assent. Children were then fitted with sEMG electrodes and reflective markers. Following quality control of measures and calibration checks, participants moved to the study area and watched a DVD for 5 min. Each child then proceeded to play electronic games in the following order: handheld, gamepad, keyboard, wheel, EyeToy. The order was selected to minimize recovery required between trials to keep session duration as short as possible (1.5 hr). Two samples of motion and sEMG were captured while the children played with each device for 5 min.

2.6. Statistical Analysis

A multivariate mixed model analysis of variance (MANOVA) with device as the within-subjects factor and gender as the between-subjects factor was performed including all relative movement dependent variables. As there was no effect of gender, nor any Gender × Device interaction, a simpler MANOVA with device as the within-subjects factor is reported here. Huynh-Feldt epsilon corrections were used as Mauchly's test indicated a lack of sphericity. Within-subjects contrasts were used to compare between devices. A critical alpha level of 0.01 was used. A similar analysis is reported for muscle activity variables. Missing values were replaced with condition means. All analyses were performed with SPSS v13.0 (SPSS Inc., Chicago, IL).

3. RESULTS

Table 1 shows the mean (standard deviation) relative motions across the device conditions for each body segment. Motion was moderately correlated across the various body segments (see Table 2). The MANOVA showed a significant difference for device (Wilks's ($\Lambda = 0.101$), $F(30,362) = 9.31$, $p < .01$, and univariate analyses showed this was true for each segment $F(5,95 > 44.63$, $p < .01$, Huynh-Feldt epsilon = .216–.337). Figure 2 shows the motion at each body segment with letters showing significantly different groups based on pairwise contrasts. EyeToy had considerably greater motion at all body segments ($p < .01$). Wheel had slightly

Table 1: Relative Body Segment Movement Across the Different Devices

	DVD	*Handheld*	*Gamepad*	*Keyboard*	*Wheel*	*EyeToy*
Sacrum—ground	5.2 (3.0)	6.0 (2.9)	5.3 (1.7)	4.9 (2.2)	4.5 (1.4)	22.6 (9.2)
Foot—sacrum	9.3 (4.6)	10.1 (5.2)	8.6 (3.4)	7.1 (2.6)	7.1 (1.6)	36.3 (19.0)
Head—sacrum	6.4 (2.9)	7.9 (3.0)	6.8 (2.2)	6.0 (2.1)	6.0 (1.5)	25.2 (11.0)
Shoulder—sacrum	6.6 (2.7)	7.6 (3.3)	6.8 (1.8)	6.1 (2.4)	6.5 (1.6)	26.2 (11.2)
Wrist—shoulder	5.6 (1.1)	7.8 (3.1)	6.6 (1.9)	5.1 (1.1)	9.4 (2.2)	63.2 (23.6)
Thumb—wrist	7.2 (2.6)	7.5 (2.5)	6.4 (2.0)	6.8 (2.9)	8.8 (2.5)	38.0 (12.9)

Note. Values are mean meters per minute, standard deviations in parentheses.

Table 2: Pearson Correlations Between Relative Movement at Different Body Segments

	Sacrum – Ground	*Foot– Sacrum*	*Head– Sacrum*	*Shoulder– Sacrum*	*Wrist– Shoulder*	*Thumb– Wrist*
Sacrum–ground	1.00	.78	.90	.90	.48	.46
Foot–sacrum	.78	1.00	.78	.81	.53	.39
Head–sacrum	.90	.78	1.00	.87	.57	.44
Shoulder–sacrum	.90	.81	.87	1.00	.62	.51
Wrist–shoulder	.48	.53	.57	.62	1.00	.71
Thumb–wrist	.46	.39	.44	.51	.71	1.00

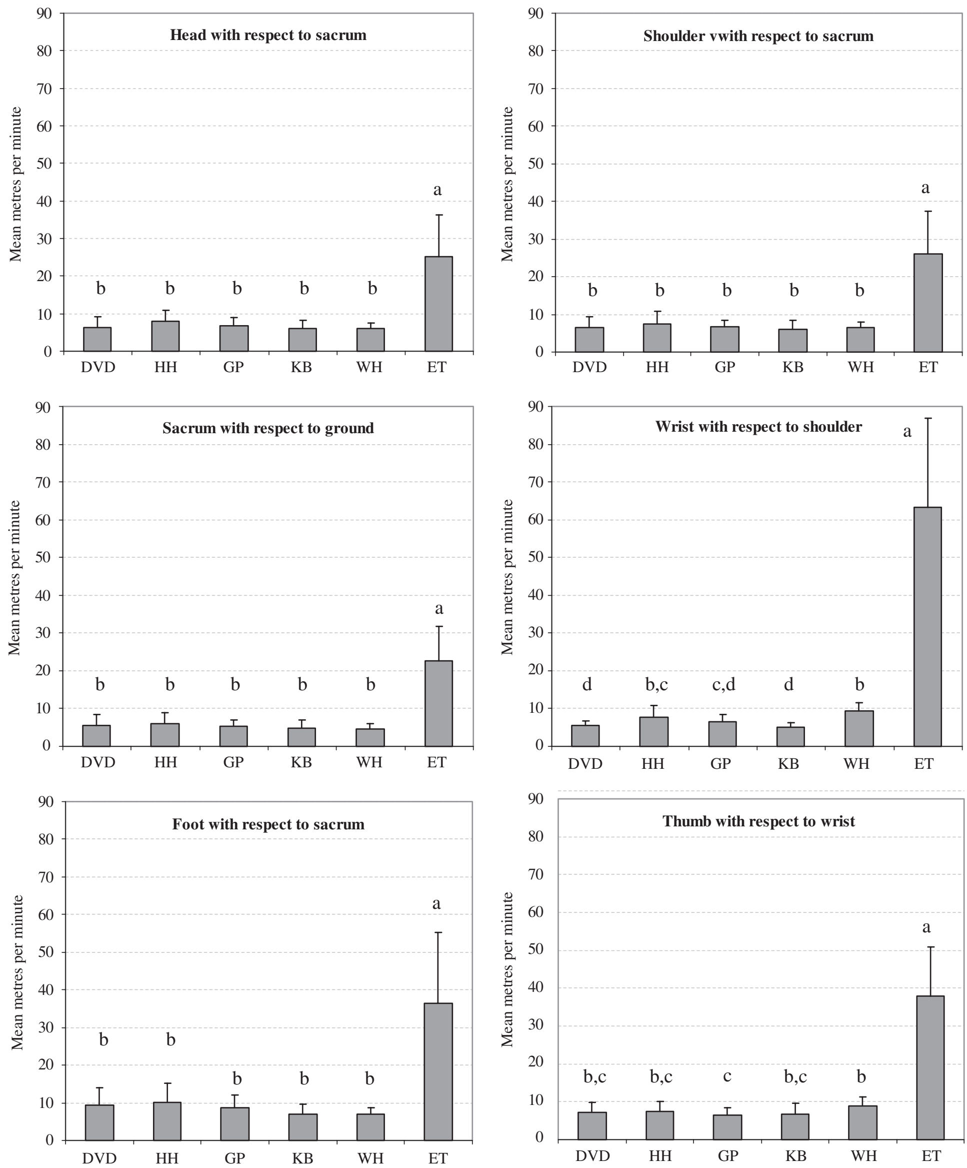

FIGURE 2 Pairwise contrast results for body segment movement across the different devices.

Note. Letters show statistically equal groups. HH = handheld; GP = gamepad; KB = keyboard; WH = wheel; ET = EyeToy.

greater ($p < .05$) motion than DVD, gamepad and keyboard devices at the wrist segment, with a trend for greater motion than handheld ($p = .061$). Wheel also had significantly greater motion than gamepad at the thumb segment. There were no other motion differences between devices.

Table 3: Muscle Activity Across the Different Devices

	DVD	*Handheld*	*Gamepad*	*Keyboard*	*Wheel*	*EyeToy*
Cervical erector spinae	0.046 (0.024)	0.078 (0.039)	0.053 (0.031)	0.063 (0.040)	0.069 (0.040)	0.122 (0.063)
Upper trapezius	0.020 (0.014)	0.022 (0.018)	0.046 (0.041)	0.077 (0.063)	0.145 (0.201)	0.225 (0.135)
Anterior deltoid	0.013 (0.011)	0.013 (0.008)	0.025 (0.027)	0.027 (0.027)	0.089 (0.083)	0.224 (0.189)
Wrist extensors	0.020 (0.022)	0.033 (0.023)	0.056 (0.053)	0.055 (0.057)	0.080 (0.084)	0.072 (0.040)
Lumbar erector spinae	0.031 (0.058)	0.034 (0.045)	0.039 (0.057)	0.055 (0.062)	0.061 (0.079)	0.252 (0.163)
Rectus femoris	0.014 (0.007)	0.014 (0.009)	0.017 (0.011)	0.015 (0.009)	0.018 (0.010)	0.164 (0.109)

Note. Values are mean unnormalized root mean square milliVolts (mV), standard deviation in parentheses.

Table 4: Correlations Between Activity Levels in Different Muscles

	Cervical Erector Spinae	*Upper Trapezius*	*Anterior Deltoid*	*Wrist Extensors*	*Lumbar Erector Spinae*	*Rectus Femoris*
Cervical erector spinae	1.00	.44	.48	.61	.41	.62
Upper trapezius	.44	1.00	.77	.60	.58	.49
Anterior deltoid	.48	.77	1.00	.55	.64	.57
Wrist extensors	.61	.60	.55	1.00	.64	.52
Lumbar erector spinae	.41	.58	.64	.64	1.00	.52
Rectus femoris	.62	.49	.57	.52	.52	1.00

Table 3 shows the mean (standard deviation) sEMG across the device conditions for each muscle. Muscle activity in different muscles was moderately correlated (see Table 4). The MANOVA showed a significant difference for device (Wilks's ($\Lambda = 0.043$), $F(30,362) = 51.38$, $p < .01$, and univariate analyses showed this was true for each muscle $F(5,95 > 9.82$, $p < .01$, Huynh-Feldt epsilon = .211–.444). There was also a significant linear trend for an increase across conditions for each muscle, $F(1) > 28.42$, $p < .01$. Figure 3 shows the activity in each muscle with letters showing significantly different groups based on pairwise contrasts. EyeToy had considerably greater activity at all muscles ($p < .01$). Wheel had greater muscle activity than non-EyeToy devices for anterior deltoid. DVD and handheld had less anterior deltoid muscle activity than other devices.

4. DISCUSSION

Despite the majority of children in affluent countries playing electronic games, this is the first description of movement and muscle activity during electronic game playing by children.

4.1. Sedentary Versus Active Electronic Games

When playing non-EyeToy games, children made very little movement of the trunk, as assessed by sacrum, head, and shoulder markers. Spinal muscle activity levels were also low during non-EyeToy games. CES muscle activity was slightly greater for handheld use, which may be due to the greater neck flexion observed during this activity as prior research has shown a fairly consistent relationship between neck flexion and CES activation (Straker, Burgess-Limerick, Pollock, Coleman, & Skoss, 2008). Lumbar erector spinae activity was slightly less during sitting on the floor (DVD, handheld, and gamepad) than sitting at a desk (keyboard and wheel). This may have been due to flexion relaxation as previously observed with slumped sitting postures (O'Sullivan et al., 2002).

Children made very little movement of the lower limb, as assessed by foot marker, when playing non-EyeToy games. Rectus femoris activity was also low during all non-EyeToy games. We had expected the wheel device to result in more leg movement than other non-Eyetoy games as the use of foot pedals was

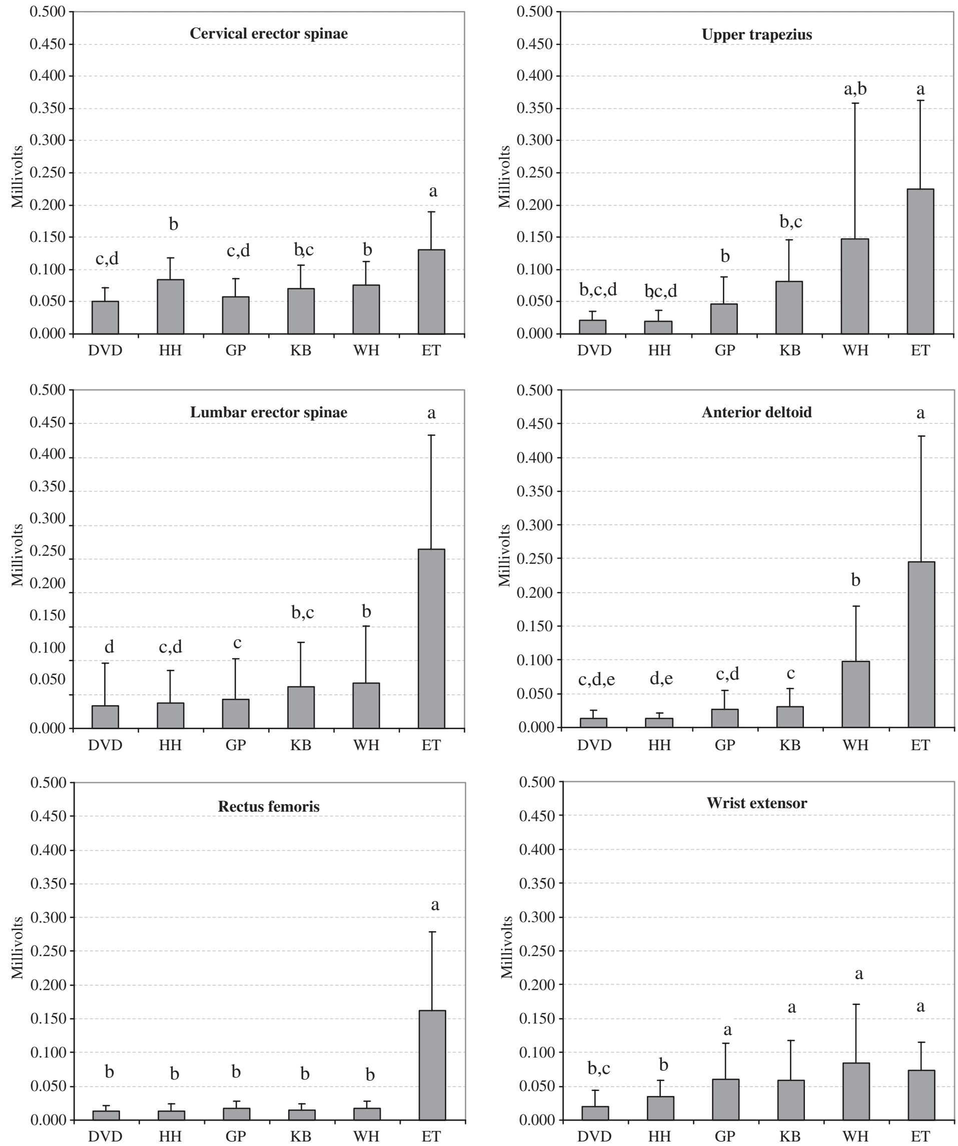

FIGURE 3 Pairwise contrast results for muscle activity (mean unnormalized root mean square and standard deviation) across the different devices.

Note. Letters show statistically equal groups. HH = handheld; GP = gamepad; KB = keyboard; WH = wheel; ET = EyeToy.

required. However, we observed children to hold the accelerator pressed flat to the floor with movements to decelerate being rare.

Using the wheel did result in more upper limb (wrist–shoulder) movement than other non-EyeToy games, and this was reflected in upper trapezius, anterior deltoid, and wrist extensor muscle activity levels. Wrist extensors and anterior deltoid are prime movers for the wheel control actions, with upper trapezius providing scapula stabilization.

The results clearly show that playing traditional electronic games required very little movement and muscle activity and therefore is indeed sedentary. Activity level was the same as watching the DVD. In contrast, the results also show that a new active-input device can require significant amounts of movement and muscle activity and children playing these games are not being sedentary. This concurs with the recent energy expenditure studies (Lanningham-Foster et al., 2006; Maddison et al., 2007; Straker & Abbott, 2007; Wang & Perry, 2006). Active electronic games therefore may have potential to increase habitual energy expenditure and reduce obesity, and this potential should be investigated in field studies.

The increased movement and muscle activity during active electronic game playing may also have an impact on musculoskeletal health. Bone, joint, ligament, tendon, and muscle tissue are known to respond to the stresses applied during movement and muscle activity, and this response may be particularly strong in the developing bodies of children (Anderson, 2000; Faigenbaum, 2001; Rowlands et al., 2004).

4.2. Active Electronic Games May Have Implications for Motor Control

Normal motor development requires maturation of neural and musculoskeletal systems plus the opportunity to practice fine and gross motor skills (White, Hayes, & Livesey, 2005). Traditional electronic game interfaces provide fine motor experience. Yuji (1996) reported evidence that electronic games improved children's fine motor performance. In a review, Whitcomb (1990) found electronic game playing lead to enhanced eye–hand coordination, dexterity, and fine motor ability and increased reaction and movement speeds in elderly participants. Rosser et al. (2007) found increased video game experience was related to increased laparoscopic surgery training performance (both speed and accuracy). However, gross motor experiences are usually associated with substantial movement of the limbs and torso by muscle activity, and our results confirm that use of traditional electronic games will not provide gross motor experience.

In contrast, our results show the new active-input electronic games require movement that may lead to improved gross motor skill. Active-input electronic games can enhance motor skill in adults following brain injury with improved locomotion and upper and lower extremity function (Sveistrup, 2004). Active-input devices have demonstrated some improvements in motor performance in case studies of children with cerebral palsy (Reid, 2002). However, there is no evidence of the effect of active-input devices on children with normal motor ability, or on children with poor motor ability. Active-input electronic games may be particularly successful for children with poor motor ability as it does not require the child to perform in front of other children. Lack of physical activity in children with poor motor ability has been attributed to their unwillingness to display their poor skill to others (Cairney, Hay, Faught, & Hawes, 2005). However, active-input electronic games may improve these children's skill by providing gross motor practice involving a high level of visual-spatial integration, but in a context that is private, and provides strong motivation by enjoyment of the game and the challenge of self-competition.

Improvements in performance in active-input electronic games are useful if they lead to improvements in real-world performance. Although there are no available data on this in children, there is evidence that balance gains from active-input device training resulted in improved real-world balance in elderly participants undergoing rehabilitation (Sveistrup, 2004). Active-input device training has also lead to greater enjoyment of rehabilitation and improved motor confidence in the real world in adults (Adamovich et al., 2005; Weiss, Rand, Katz, & Kizony, 2004). This suggests that active-input games could improve real-world motor skill in children and could increase children's confidence, which would be additionally beneficial for children with poor motor ability.

The movement measure used in this study was only a crude measure of the amount of movement and future research should investigate the quality of movement. In the current study only one example of an active-input game was used, and although it was selected to represent the movement requirements of this device, the range of movement and muscle activity requirements across different games and devices should be explored. The lack of normalization for the sEMG inhibits comparisons with other studies but did substantially reduce the burden on participants. Finally, this laboratory study does not provide any evidence about how active-input devices would be used in the home over prolonged durations; field studies are required to assess the longer term impact of these devices.

5. CONCLUSION

Children's exposure to electronic games is considerable and has lead to concerns regarding the health implications of the sedentary nature of this exposure. However, there was no prior data on the movement and muscle activity demands while children played electronic games. This study showed that children playing traditional electronic games had very little movement and muscle activity, similar to sitting and watching a DVD. In contrast, children playing a new active-input electronic game had considerable movement and muscle activity. These results suggest that active-input electronic games may be useful in developing stronger musculoskeletal systems and better gross motor skills in children, as well as increasing overall physical activity and reducing obesity.

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