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Evidence-based guidelines for the wise use of computers by children: Physical development guidelines

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Computer use by children is common and there is concern over the potential impact of this exposure on child physical development. Recently principles for child-specific evidence-based guidelines for wise use of computers have been published and these included one concerning the facilitation of appropriate physical development. This paper reviews the evidence and presents detailed guidelines for this principle. The guidelines include encouraging a mix of sedentary and whole body movement tasks, encouraging reasonable postures during computing tasks through workstation, chair, desk, display and input device selection and adjustment and special issues regarding notebook computer use and carriage, computing skills and responding to discomfort. The evidence limitations highlight opportunities for future research. The guidelines themselves can inform parents and teachers, equipment designers and suppliers and form the basis of content for teaching children the wise use of computers.

Statement of Relevance: Many children use computers and computer-use habits formed in childhood may track into adulthood. Therefore child–computer interaction needs to be carefully managed. These guidelines inform those responsible for children to assist in the wise use of computers.

Keywords: children; computers; guidelines; musculoskeletal disorders

1. Introduction

Computer use by children is common and likely to have physical, cognitive and social impacts. Previous papers have argued the need for child-specific evidence-based guidelines (Straker and Pollock 2005, Straker *et al.* 2006a,b) and presented general principles for wise use of computers by children (Straker *et al.* 2009b). One of these principles concerned the physical impact, specifically the risk of musculoskeletal disorders (MSDs) and other physical health outcomes.

The aim of this paper was to review the evidence relating to physical aspects of the child–computer interaction. A narrative review approach was selected because of the variable nature of available evidence. Based on the evidence, a set of guidelines covering physical aspects of the child–computer interaction are presented (see summary in Table 1). Whilst these guidelines can be used to guide computer use practices directly, they are also intended to be the basis for education of children, teachers and the parents of children so that child computer users are aware of the issues and develop appropriate computer-use habits to take into adulthood.

2. The physical guidelines

2.1. *Encourage a mix of sedentary tasks and whole body movement tasks*

The first few physical guidelines are all related to encouraging a mix of whole body movement tasks with the, generally, sedentary computing tasks. This guideline is aimed at providing sufficient whole body activity to facilitate appropriate neuro-musculo-skeletal development and to minimise the risk of musculo-skeletal and other health disorders.

2.1.1. *Encourage task variety*

There is a general consensus that variation of movement and load on the body is important for reducing the risk of MSDs, although Mathiassen (2006) cautioned that direct evidence for this assertion is weak. The aetiology of MSDs is multifactorial and may include workstation parameters, psychosocial stress, posture and force-related exposures related to anthropometry (size and strength), rest break schedules and individual differences in motor control strategies. All of these contribute and

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Table 1. Guidelines for desktop/notebook use to encourage appropriate physical development.

1.1	Encourage a mix of sedentary and active tasks
	1.1.1. Encourage task variety through breaks and changing tasks
	Mix computer tasks with non-sedentary/active tasks**
	Take an active break from the computer every 30–60 min **
	1.1.2. Encourage use of active input devices
	Use active input devices whenever possible**
	1.1.3. Encourage postural variety
	Encourage children to fidget and move around whilst using computers *
	1.1.4. Limit sedentary use of computers
	Limit the use of sedentary electronic equipment for leisure purposes to less than 2 h per day*
1.2	Encourage reasonable postures during sedentary tasks
	1.2.1 Encourage a range of suitable postures through appropriate workstation design
	Select/adjust workstation size to suit the child***
	Design workstations to enable a range of suitable postures**
	Use standing and sitting workstations*
	1.2.2 Encourage a range of suitable seated postures by selecting and adjusting chair appropriately
	Set seat pan height to allow feet to be supported***
	It may be appropriate to not have a backrest
	If a backrest is provided the seat pan should be shorter than thigh length and the backrest should fit the child's lumbar spine
	Avoid armrests
	Select seat style to support a range of reasonable postures
	1.2.3. Encourage suitable postures by selecting and adjusting an appropriate work surface
	Set desk height to around elbow height*
	Select large enough desk surface to permit appropriate positioning and use of keyboard, mouse and other materials
	Select a single flat thin surface
	Use document holders and inclined supports to position paper materials close to the display
	1.2.4. Encourage appropriate postures and gaze angle by selecting and positioning computer display appropriately
	Set top of display at eye height**
	Position display at about arm's length and directly in front
	Position display to avoid glare
	Select a good quality display
	1.2.5. Encourage appropriate postures by selecting and positioning keyboard and pointing device appropriately
	Select symmetrical mouse of appropriate size *
	Enable mouse use on either side of keyboard
	Provide thin flat keyboard to reduce wrist extension
	Provide a smaller keyboard for smaller children
	Provide a keyboard without numeric keypad
	Select mouse and keyboard with suitable activation forces
1.3	Encourage appropriate behaviour when using and transporting notebook computers
	Provide notebook of low weight
	Carry notebook in dual shoulder strap backpack*
	Provide external keyboard and adjust display height for larger children*
	Encourage use of appropriate alternative postures for variety
1.4	Teach children computing skills
	Learn to touch-type with minimum force*
	Learn keyboard shortcuts to reduce mouse use
	Learn to use software
1.5	Teach children to respond to discomfort*

interact under relatively low biomechanical load conditions (Jensen *et al.* 1993, Johnson *et al.* 2000, Wahlstrom *et al.* 2000, Dennerlein and Johnson 2006, Johnson and Blackstone 2007), which may be sustained for many hours. Although the value of task variation is intuitively appealing, it may therefore be difficult to empirically isolate the effects of variation. Westgaard (2000) noted that it is difficult to detect risk factors at low biomechanical exposures.

Attempts to increase exposure variation through task variation have included introducing pauses within work tasks (e.g. taking breaks), deliberately working using a mixture of keyboard and mouse use, switching hands when using the pointing device (e.g. mouse), switching between pointing devices with different biomechanical demands (e.g. a mouse and a trackball) and introducing different work tasks (e.g. intentionally breaking up computer work with meetings).

2.1.1.1. Task variety through pauses. While there have been some benefits of introduced pauses, and software that introduces pauses into the work pattern is used by more than one million computer users (Slijper *et al.* 2007), evidence for the benefit of short pauses is mixed. A review of workplace interventions by Brewer *et al.* (2006) found mixed evidence for the effect of rest breaks on musculoskeletal outcomes and insufficient evidence to conclude that rest breaks affected visual outcomes. However, limited rest break opportunities have been linked to musculoskeletal problems in adult computer users (Bergqvist *et al.* 1995). The timing and length of pauses may be influential; Blangsted *et al.* (2004) found no difference in electromyographic levels with 30 s vs. 4 min breaks in a one-handed keying task. Muscle activity during the breaks did not differ between keying and non-keying sides and during the pauses it was above resting level. Hagberg and Sundelin (1986) found a significant negative correlation between spontaneous pauses and static trapezius load, but not between introduced pauses and static load. The introduced pauses were, however, associated with a lower rating of perceived exertion. In a study of the efficacy of pause software, spontaneous pauses were reported to correspond closely to the timing of introduced micropauses. However, the software enforced longer pauses (greater than 5 min) before the operator would naturally take a break (Slijper *et al.* 2007).

Performance decrements have been noted in adult computer operators after approximately 45–50 min of computer work (Floru *et al.* 1985, Gao *et al.* 1990) and it has been recommended that breaks be taken after 40–60 min (Floru *et al.* 1985, Gao *et al.* 1990, Kopardekar and Mital 1994, Boucsein and Thum 1995). During simulated directory assistance work, comparison of a 60 min on/10 min off work/rest schedule with a 30 min on/10 min off schedule revealed no difference in performance (Kopardekar and Mital 1994). In contrast, Balci and Aghazadeh (2004) found the introduction of a micropause regimen (breaks of 30 s to 3 min every 15 min) to be superior to two longer rest break schedules in terms of musculoskeletal discomfort, eyestrain and performance. In another study, four supplementary 5 min work breaks inserted into the usual workday pattern of 51 data entry operators were found to reduce musculoskeletal discomfort and eyestrain, with no decline in productivity (Galinsky *et al.* 2007). There is no consensus regarding the optimal schedule for work/rest breaks and it is likely to be dependent upon many factors, including the task, input device and individual – for example, highly repetitive keying tasks such as data entry may benefit from different pause regimens when compared to mouse-intensive tasks such as computer-aided design.

The introduction of pauses into computing tasks by children appears not to have been examined directly. Computer use at home has been reported to be characterised by longer maximum durations than at school (Harris and Straker 2000), suggesting that breaks during home use may be more important.

It is noteworthy that studies of introduced rest breaks for adults do not tend to find negative effects on either discomfort or productivity and some studies have reported beneficial effects. It is likely that the introduction of pauses and rest breaks can be of benefit, but a particular schedule of rest breaks is difficult to justify. The task of identifying the most effective rest break schedules for the many different work patterns, which are likely to occur for both adults and children, is a daunting one.

2.1.1.2. Task variety through changing tasks. Different computer tasks such as keyboard entry, numerical data entry, mouse-intensive tasks and reading from a display or document apply differing stresses to the body. Mouse tasks tend to be more constrained and have lower variation in forearm muscle activity than keyboard tasks (Dennerlein and Johnson 2006b). A study of Irish children aged 9 years found that pain after a computing session was related to the task performed, with increased neck pain for those children who primarily used the mouse (Breen *et al.* 2007). Mouse use has also been associated with musculoskeletal symptoms in adult users (Ijmker *et al.* 2007). Keyboard tasks are associated with greater variation but have less neutral wrist postures and larger wrist velocities. Different input devices such as trackpoints also affect which structures are loaded (Fernström and Ericson 1997). Therefore, a mixture of keyboard and mouse use may provide some exposure variation (Dennerlein and Johnson 2006b).

Computer tasks tend to offer less variation in posture and muscle activity than paper-based tasks, both for adults (Wærsted and Westgaard 1997, Straker *et al.* 2009b) and children (Straker *et al.* 2008c, 2009d). Postures during computer work, however, tend to be more neutral and symmetrical than those using old IT (paper-based information technology) (Straker *et al.* 2008b, 2009d). A mixture of old and new (electronic based) IT tasks may therefore provide some variation and be of benefit.

Perhaps the most effective method to encourage physical variety is to mix computer tasks with non-IT tasks. For example, alternating computer data entry with delivering mail. Non-IT tasks have been found to provide more postural and muscle activity variation in both adults and children (Ciccarelli *et al.* 2006, 2009, Maslen and Straker 2009).

Children do not always use computers in a similar manner to adults – they may share school computers between two or more users (Sotoyama *et al.* 2002, Breen *et al.* 2007) and at home they frequently use other forms of technology such as phones and MP3 players simultaneously with the computer (Kent and Facer 2004, Roberts *et al.* 2005, Foehr 2006). Such usage patterns may inherently offer more postural and load variation for the body and should, therefore, not necessarily be discouraged, providing they do not interfere markedly with performance, for example, of homework tasks. However, children may also get highly involved in a computer task and may continue even when experiencing discomfort (Harris and Straker 2000), so it is important to encourage rest breaks or task changes.

> Based on the available evidence, it is recommended that children should be encouraged to take a break from computer work every 30 min and not be allowed to work more than 60 min without a break from the computer These breaks should be physically active and meaningful to the child, rather than a sedentary break (e.g. sitting watching TV, playing video games or using a mobile phone).

It is anticipated that it will be fairly easy for teachers to implement this guideline at school, as children frequently need to change rooms or move around within a classroom to perform their school tasks. However, there may be some longer computing lessons where teachers will need to introduce postural changes by having children get up and perform a different activity. Developing good task variety habits at a young age in school and home will assist in the maintenance of these habits into adulthood. It is anticipated that it will be challenging for parents and children to learn and maintain good task variety habits at home, as data show prolonged durations of sustained computer use are more common at home (Harris *et al.* submitted).

2.1.2. Encourage use of active input devices where possible

Active input technology is a relatively recent introduction to the computer/electronic game arena, whereby users interact with a computer through gross motor movements. These movements are registered by devices such as a USB camera (e.g. Eye-Toy, Sony), 'dance mat', which responds to foot pressures (Dance Dance Revolution; Konami, Tokyo, Japan) or a hand-held wireless accelerometer-based controller (Wii; Nintendo Co. Ltd., Kyoto, Japan). Such devices encourage less sedentary interaction with the computer or electronic game and therefore are thought to offer health advantages over traditional inputs devices such as joystick controllers, mouse or keypad.

A few recent studies have examined the metabolic effects of active input devices in comparison to sedentary activities such as watching television or playing traditional computer games (Lanningham-Foster *et al.* 2006, Graves *et al.* 2007, Maddison *et al.* 2007, Straker and Abbott 2007). Increasing the metabolic load, over the resting level, varies depending upon the input device and games being played. Both the EyeToy and dance mat can elicit substantial increases in energy expenditure, levels consistent with moderate intensity sporting activities such as jogging and basketball. However, sensible usage patterns and rest breaks are required as extremely intensive use has elicited acute pain such as the case of 'Wii-itis' reported by Bonis (2007). Despite this risk, the use of these devices in preference to traditional computer game input devices may be beneficial. A pilot study has found that access to traditional sedentary electronic game devices decreases physical activity over the week, but that access to only active input electronic game devices can increase weekly physical activity (Straker *et al.* 2008e).

> Based on the available evidence, it is recommended that children should use active input devices whenever possible.

Nearly all of the active input applications for children to date have been games. However, educational programs could also adopt this technology and this may be particularly effective for children who learn well when being active. Encouraging children to switch from a sedentary electronic game to an active electronic game may be easier for parents than not allowing children to play electronic games. Schools could encourage this by providing active electronic game alternatives and adopting active input learning programs when these become available.

2.1.3. Encourage postural variety

The National Institute for Occupational Safety and Health in the United States of America reviewed the literature on health effects associated with occupational work and concluded that there was strong evidence for an association between static or specific postures of the neck or neck/shoulder and MSDs in these regions (Bernard 1997). Whilst high wrist velocities and accelerations have been reported during keyboard work (Dennerlein and Johnson 2006b), computer tasks generally require a low level of effort (Dennerlein and Johnson 2006a, Johnson and Blackstone 2007) and little movement (Straker *et al.* 2008c). For example, when a computer-based task was compared to a book/paper-based task, average postures and minimal levels of muscle activity were greater in the computer-based tasks, for both adults (Wærsted and Westgaard 1997, Straker *et al.* 2009c) and children (Ciccarelli *et al.* 2006, Straker *et al.* 2008c, 2009d). It is therefore important to encourage postural variation during computer tasks.

Children tend to have more postural and muscle activity variation than adults performing an identical computer task (Johnson and Blackstone 2007, Maslen and Straker 2009). This may be related to their smaller size – if using input devices designed for adults, for example, a greater relative excursion of the fingers or forearm may be required to move the cursor a specific distance or move between specific keys, compared to the movement for a larger, adult upper limb. Children (5–8 years old) using an adult-sized mouse or keyboard were found to have greater mean ulnar deviation and less wrist extension than their same-sex parent (Blackstone *et al.* 2008). They also had nearly twice the range of motion during mouse use and three times the range during typing for both wrist flexion/extension and ulnar deviation.

The greater postural variation exhibited by children during computer tasks may also be related to computer experience – more years of computer use by adults may lead to more efficient keyboarding and/or mouse skills. Other factors such as learning and increased coordination and motor control may also be involved. Regardless of the cause, it is suggested that adults should not discourage, and actually promote, children to move around/'fidget' during computer use.

It is also important to recognise that there is large individual variation in movement patterns. Observations of children in a classroom situation revealed that some children moved continuously while others had very static postures (Murphy *et al.* 2004). These more static postures were associated with neck and upper back pain. Large inter-individual variation in load for a given task is also inherent for adult populations (Westgaard 2000). Associations between static muscle activity and pain/discomfort have also been reported for adults (Jensen *et al.* 1993, Veiersted *et al.* 1993, Hagg and Åström 1997) and symptomatic office workers show differences in motor control to their asymptomatic colleagues (Szeto *et al.* 2009).

Computer use duration in children increases with age. When children start to use computers, ergonomists, health professionals, teachers and parents should teach them the importance of periodically altering their posture and reducing their time spent in static postures. This may be particularly influential in maintaining their musculoskeletal health as they grow and mature into adults. In a study of nearly 900 Australian adolescents, the amount of computer use (hours per week) was related to habitual sitting posture (i.e. posture when not using a computer), with increased head, neck and thorax flexion during usual sitting related to a greater 'dose' of computer use (Straker *et al.* 2006c). This study highlights the importance of developing appropriate guidelines for younger computer users in order to minimise musculoskeletal problems for future generations. Workstations influence posture and postural options and should therefore be designed to encourage variety.

> Based on the available evidence, it is recommended that children should be encouraged to move around and periodically alter their posture whilst using computers. Their computer workstations at home and school should be designed to promote a variety of working postures (see below).

2.1.4. Limit sedentary leisure use of computers and encourage children to engage in other non-sedentary activities

Two categories of evidence are pertinent to this guideline: 1) what computer use does physically to the child; 2) what activities the child may be missing out on while spending extended periods on the computer.

With regard to computer use displacing physical activity and the associated health risks, the evidence is weak for children overall. Studies of the relationship between obesity and computer use have generally demonstrated either no relationship (Wake *et al.* 2003, Janssen *et al.* 2005, Burke *et al.* 2006) or a partial effect (Kautiainen *et al.* 2005, Lajunen *et al.* 2007). The association between the duration of computer use and body mass fat percentage is different from the pattern associated with television watching. In addition, the association between computer use and decreased physical capacity also appears to be weak. Many children are able to combine moderate to high levels of computer use with physical activity at least equivalent to that undertaken by children who use computers less (Ho and Lee 2001, Olds *et al.* 2004, Mutunga *et al.* 2006). However, for some children, computer use has been shown to limit physical activity. Straker *et al.* (2006d) found a negative relationship between computer use and vigorous physical activity on weekends for 5-year old children. Attewell *et al.* (2003) found that children who spent less than 8 h per week using a computer did not differ from non-users in time spent playing sport. However, heavier users spent 3 h less per week on sport and outdoor activities than non-users. Increasing computer-based sedentary activities has been identified as a serious health risk for adults (European Agency for Health and Safety at Work 2005, Straker and Mathiassen 2009) and encouraging sufficient non-sedentary activity for young people is likely to be an important health policy.

Whilst computer use has the potential to displace some physical activity, adverse musculoskeletal consequences in adults, as a result of prolonged or intensive computer use, indicate that it may be wise to limit the amount of time children spend using a computer. Pain and musculoskeletal discomfort in children, teenagers and adults has been shown to be related to the duration of computer use (Berqvist *et al.* 1995, Blatter and Bongers 2002, Gerr *et al.* 2006, Gillespie *et al.* 2006, Hakala *et al.* 2006, Chang *et al.* 2007, Ijmker *et al.* 2007, Jacobs and Baker 2002, Marcus *et al.* 2002). The problem may be exacerbated for children because they tend to use computers at workstations that are not suitable for their morphology (Oates *et al.* 1998, Zandvliet and Straker 2001, Dockrell *et al.* 2007). In addition, since children are still developing in terms of spinal posture, musculoskeletal system and lifestyle habits, there is concern that patterns of computer use in childhood could affect the individual in adulthood.

The body of research evidence is increasing and showing that documented musculoskeletal problems found in intensive adult computer users are now occurring in children. The evidence from adult computer users shows an increased risk for developing musculoskeletal symptoms when computer use exceeds 4 h per day. However, for children, it is difficult to pinpoint a safe threshold beyond which symptoms, disorders or physical fitness decrements may occur. Hakala *et al.* (2006), using a self-report survey in adolescents, demonstrated that 2–3 h of computer use per day posed an increased risk for neck and shoulder pain and more than 5 h per day was a threshold for lower back pain. A recent campaign in Western Australia, entitled 'Unplug + Play' (http://www.heartfoundation.org.au/Healthy_Living/Kids/Parents'_Resources/Unplug_and_Play.htm), recommended that children spend no more than 2 h per day using screen-based entertainment (computers, TVs, gaming devices, mobile phones, etc.) for entertainment purposes (i.e. excluding school homework). This campaign is supported by a number of health-related bodies relating to cardiovascular health, diabetes and cancer and is an expression of the level of concern that authorities have for children and the increasing use of screen-based entertainment.

> Based on the available evidence, it is recommended that children's use of sedentary screen-based media (computers, TVs, gaming devices, mobile phones, etc.) for leisure purposes should be limited to a maximum of 2 h per day.

2.2. *Encourage reasonable postures during sedentary tasks*

Whilst the first few guidelines limit the total duration and prolonged uninterrupted periods of sedentary computing tasks, the next few guidelines concern the maintenance of appropriate postures when performing these tasks.

Cook and Burgess-Limerick (2003) noted that there is a consensus developing that there is not one ideal posture or set-up for computer workstations, but rather that users should be guided to use a range of suitable postures throughout the day. Computer use involves both physical and visual interaction and these tend to determine the postures assumed. The design of the workstation chair, desk, display and control equipment is thus critical to encourage appropriate interactions and postures.

2.2.1. *Encourage a range of suitable postures through appropriate workstation design*

Specific workstation dimensions and parameters have been shown to affect posture, muscle activity and musculoskeletal discomfort or disorders in both adults and children. Research describing chair, desk, display and input devices will be reviewed individually in the following sections. The current workstation situation for children using computers is described below. This description primarily pertains to school settings as there is little research detailing home computer workstations for children despite evidence that home use is often considerably greater.

There is little doubt that children at school frequently use furniture that is not suited to their anthropometry. A number of studies from many different countries have shown discrepancies between children's anthropometry and the chairs and desks that are available at school (e.g. Milanese and Grimmer 2004 – Australia, Parcells *et al.* 1999 – USA, Panagiotopoulou *et al.* 2004 – Greece, Savanur *et al.* 2007 – India).

One of the first studies to highlight the disparity between computer workstations and children's morphology was that of Oates *et al.* (1998). Of 95 children aged between 8 and 12 years, Rapid upper limb assessment (RULA) ratings indicated that no child was working in an acceptable postural range. The sample for this study included approximately equal numbers of children from the 5th, 50th and 95th percentiles for stature, which effectively means that two-thirds of the sample were at the extremes of anthropometry for their age; however, the results of this study are still a cause for serious concern. More than half of the computer displays were at a height that exceeded recommendations for adult users and none of the computer workstations observed was adjustable. The chair dimensions were 'marginally adequate', although children were still sitting with the feet unsupported, and the height adjustability of the chair was lacking. Kelly *et al.* (2009) found similar results in a sample of 40 Irish school children and Zandvliet and Straker (2001) found that schools in Canada and Australia were rated highly in terms of the capability of the computer hardware, but the ratings of the workstation and visual environment faired poorly.

A total of 200 Japanese schools were surveyed with somewhat better results. Height-adjustable desks were seldom used in any of the schools; however, although not prevalent in elementary schools, height-adjustable chairs were common in junior high and high schools (Sotoyama *et al.* 2002). In contrast, Noro *et al.* (1997) found a large mismatch between Japanese primary school children and their computer workstations. Szeto (2003) reported that in Hong Kong school computer displays were commonly placed on top of the central processing unit, due to limited space availability, and chairs were non-adjustable. Even if different sizes of school furniture are available, schools may not always distribute them appropriately. Bennett (2002) reported that although three sizes of chair were available in a Californian school, some of the younger classes had only the largest chairs; conversely, some of the older classes had only medium size chairs.

Only limited data are available regarding workstation set-up for children using computers in the home. Jacobs and Baker (2002) found that children from the USA generally used computers at home on furniture that was not designed for computer use, with 86% of the sample reporting that their heels did not touch the ground while using the computer. There was a trend for a relationship between self-reported musculoskeletal discomfort and using furniture that was not designed for computer use. Keyboard and display placement were also poor. Space limitations for Hong Kong children at home were reported to limit the availability of a computer desk in some households (Szeto 2003) and most households shared a computer between children and adults. This latter situation is likely to be the usual scenario for many children throughout the world. Roberts *et al.* (2005) reported that 31% of children in the USA had a computer in their bedroom and a further 12% had their own notebook computer. This indicates that over half of the children share a computer with their family, probably on an adult-sized workstation.

Molenbroek *et al.* (2003) described various ways in which furniture can be fitted to the end user. In a school environment, the most common approach, to minimise cost, is to provide fixed height, non-adjustable furniture of various sizes. Ideally, for computer workstations used by a wide age range of children, it would be preferable for schools to provide adjustable furniture. Simple, practical and cost-effective adjustable furniture solutions have been shown to reduce musculoskeletal discomfort in adult users (Mekhora *et al.* 2000). In 4–17 year old children, workstation adjustment to match the stature of the individual child was shown to promote more neutral head postures (Straker *et al.* 2002). In addition, Laeser *et al.* (1998) demonstrated that a workstation set-up that was adjusted to suit the anthropometry of individual children improved RULA scores. The importance of correctly configuring workstations to encourage beneficial postures is therefore well established.

The definition of what constitutes a good seated posture is the subject of some debate. However, rather than just the traditional seated posture with an upright trunk and thighs perpendicular to the trunk (see review by Corlett 2006), an array of seated postures is now considered acceptable, including forward and backward inclined positions (Mandal 1982, Nag *et al.* 2008). In a review of guidelines for adult computer workstations, Cook and Burgess-Limerick (2003) concluded that the array of seated postures that can be adopted (back-leaning, upright, forward-leaning) each have specific advantages and disadvantages, and an ability to vary postures and easily adjust furniture to facilitate a range of postures was desirable. This range of furniture adjustability with a continuum of seated posture options is likely to apply to the workstations of children.

Standing-only workstations are related to increased musculoskeletal discomfort with prolonged use, whereas workstations that allow sitting and standing have been shown to reduce musculoskeletal discomfort in adults (Roelofs and Straker 2002). Standing computer workstations for short duration tasks may therefore be suitable for children. Aside from being seated at a desk, children can use computers standing and with notebook computers sitting on floor/bed and lying (see section 1.2.6).

Recently, active workstations (where computer use is performed whilst the person walks slowly on a treadmill or cycles slowly on an exercise bike) have been advocated for adult office workers as a way of increasing non-exercise physical activity and the subsequent health benefits (Levine and Miller 2007, Thompson *et al.* 2008, Straker and Mathiassen 2009). Whilst a small typing and slightly larger mousing performance decrement has been measured during the use of these workstations, this performance loss is probably outweighed by the health gains (Straker *et al.* 2009b). No studies on children using these active computer workstations have yet been reported.

Based on the available evidence, it is recommended that school computer workstations should be adaptable in order to accommodate the size ranges of the children using them. Computer workstations used in the home should match the size and shape of the child. All computer workstations should support a range of reasonable postures. Standing and sitting workstations should be used.

2.2.2. *Encourage a range of suitable seated postures through appropriate chair selection and adjustment*

Selection and adjustment of an appropriate chair for computer-based work is an important component of workstation optimisation. Associations between sitting postures and spinal pain or discomfort have been described for both adults and children (Trevelyan and Legg 2006). Whilst there is general agreement that the feet should be able to be positioned flat on the floor during seated work, there is less consensus regarding factors such as seat slope, the orientation and use of a backrest and the presence of armrests on the chair.

Mismatches between children's anthropometry and school chairs have been widely reported (Parcells *et al.* 1999, Legg *et al.* 2003, Milanese and Grimmer 2004, Gouvali and Boudolos 2006, Murphy *et al.* 2007, Saarni *et al.* 2007, Savanur *et al.* 2007). Corlett's (2006) review of research-based seating requirements for workplaces and schools noted that school furniture was inadequate as a result of decisions not related to what pupils needed. Some studies (e.g. Milanese and Grimmer 2004) have found chairs to be too low, others too high (Parcells *et al.* 1999, Panagiotopoulou *et al.* 2004, Gouvali and Boudolos 2006, Chung and Wong 2007, Savanur *et al.* 2007) and Saarni *et al.* (2007) reported that chairs in Finnish schools were too high if compared to a European standard, but too low in relation to individual anthropometric measures. Molenbroek *et al.* (2003) compared the fit of school chairs based on popliteal height to that based on stature and concluded that the selection of chairs based on stature can result in a misfit of up to 7 cm in chair height.

The recommendation that the height of the front of the seat pan should correspond fairly closely to the (shod) popliteal height is perhaps the least controversial aspect of seating ergonomics. Popliteal height has been postulated to be the most relevant dimension for seat selection (Barrero and Hedge 2002). This position enables the individual to support the feet flat on the floor and reduces pressure on the back of the thighs (Pheasant 1996, Parcells *et al.* 1999, Milanese and Grimmer 2004). Some of the load due to body weight is transmitted through the feet while sitting (Nag *et al.* 2008), thereby reducing the load that is transmitted to the seat pan under the buttocks. In what appears to be the sole study of children's home computer workstations, self-reported pain was inversely related to reporting that the feet were positioned flat on the floor (Jacobs *et al.* 2006). It is recommended that the seat pan height allows the child's feet to be flat on the floor.

Should children use backrests? In an experimental setting, the use of backrests on a chair has been shown to reduce the load distributed at the seat (Nag *et al.* 2008) and is thereby thought to reduce spinal loading. Leaning against a backrest can also assist with the retention of the lumbar curve during sitting (Corlett 2006). Seated postures without a backrest have been reported to increase load within the spinal discs to a level that may restrict nourishing of the disc in adults (Colombini *et al.* 1986). However, observations of children working at school have shown that children often work without using a backrest, even if one is present (Murphy *et al.* 2004, Ciccarelli *et al.* 2006, Breen *et al.* 2007). In addition, children who used a saddle-style seat with no backrest for 2 years were found to have improved trunk muscle strength, better sitting and standing postures and less musculoskeletal discomfort than a control group who used traditional school chairs with backrests (Koskelo *et al.* 2007). Breen *et al.* (2007) also reported that children who did not have a backrest tended to adopt better postures than those with a backrest. Geldhof *et al.* (2007) reported that 8–12 year old children used a backrest for 36% of the time and Cardon *et al.* (2004) observed backrest sitting for 30% of the lesson time. It is likely that the fit of furniture to the individual's anatomy is influential in the use of backrests – seat pan depth is a parameter that has been reported often to be mismatched to children's morphology for school furniture (Parcells *et al.* 1999, Milanese and Grimmer 2004, Panagiotopoulou *et al.* 2004, Savanur *et al.* 2007). A seat pan that is too long suggests that the child would not comfortably be able to lean back against the backrest without causing pressure behind the knees or slumping.

A study of the buttock contours of seated 16–17 year old Australian students revealed a significant difference between the sitting posture assumed whilst typing and sitting back against the backrest (Tuttle *et al.* 2007). Switching between these positions may occur when typing then reading from the screen or looking at a teacher or a display board and suggests some benefit for postural variation. A study of prolonged (2 h) sitting for young adults prompted the recommendation that chair design should allow individuals to vary postures easily, rather than constraining posture to an assumed ideal posture (Callaghan and McGill 2001). Whilst it appears that a suitable backrest can reduce loading on the lower trunk, a chair without a backrest may encourage more trunk activity and general movement (Cardon *et al.* 2004). If a backrest is present on the chair, it should be adjustable in both horizontal and vertical directions.

Similarly to backrests, armrests on chairs have been shown to reduce loading through the seat pan during sitting for adults (Nag *et al.* 2008). The presence of armrests on chairs has been associated with a lower risk of neck and shoulder disorders in a prospective study of newly employed computer users (Marcus *et al.* 2002). Forearm support during computer work is known to be of benefit in reducing musculoskeletal stress and this will be discussed in the section relating to computer desks. Delisle *et al.* (2006a) suggested that alternating forearm support from the desk surface and from chair armrests could be of benefit by introducing postural variation. However, the use of armrests for children's seating has not received any scientific investigation, hence their efficacy and ideal positioning with reference to body dimensions is unknown. Fixed armrests that are too big or too high could be expected to constrain posture, particularly that of the upper limb, and may prohibit the chair being positioned close enough to the table to permit forearm support on the desk and allow for the child's smaller reach when using input devices. Armrests also need to be adjustable anteriorly and posteriorly and laterally as well as in height to ensure an appropriate position to provide support. Whilst it is likely that armrests that are at an optimal position may provide the benefits that are documented for adults, given the difficulty in ensuring an appropriate armrest position, it may be wiser to provide chairs without armrests. This may have the additional advantage of allowing greater postural variability.

Seating intervention studies have been conducted to determine whether different styles of chairs offer any advantage to traditional chairs. There have been some promising results, including those of a Finnish study by Koskelo *et al.* (2007). This study included a control group, who continued to use traditional, non-adjustable furniture, and an experimental group, who received adjustable tables and adjustable, saddle-type chairs that had no backrest and encouraged a more open angle of the hip, in line with Mandal's (1982) recommendations. At the end of the 2-year study, the experimental group had better sitting and standing spinal postures, greater trunk muscle strength and fewer reports of discomfort. Whilst these results are encouraging, limitations of this study include the small sample size (15 matched pairs) and the inability to extract separate effects of sloping desk, adjustable furniture and saddle-style of seat. In another study of the benefits of alternative seating, Linton *et al.* (1994) observed that students using newer furniture had fewer reports of discomfort but differences in actual sitting postures were small and the children did not automatically sit 'properly' with the new furniture. Whilst new seat designs may offer some promise, the current body of evidence is not sufficient to inform specific recommendations.

Schools are in an extremely difficult position when it comes to providing appropriately sized seating for computer (and traditional school work) tasks. Garcia-Acosta and Lange-Morales (2007) recently attempted to define chair sizes for Colombian school children aged from 5 to 18 years. In order to minimise costs it was desirable to have as few sizes as possible. Upon further analysis it was determined that at least five sizes of furniture were required to encompass the entire age range and variation between the 5th and 95th percentiles students. Bennett (2002) has shown that, even when multiple sizes of school furniture are available, they may not necessarily be distributed between classes with ergonomic principles in mind. Other considerations that may differ between adult workplaces and those of schools include the range of ages and sizes that may be required to share one computing facility, the desirability in some classrooms for the chairs to be stackable, the need for teachers to be able to view computer displays and interact with students and shared use of single computers by two or more students. Seating requirements are therefore likely to be considerably more complicated in educational environments. Whilst better designed furniture may be desirable, funding is typically limited. However, the chair is an easily adjustable component of the workstation set-up and children are expected to adopt seated postures for much of their 'working' day. Chair size, therefore, should suit the child's size – if this cannot be done through the purchase of adjustable furniture, basic improvements in seating position may be achievable through simple interventions, such as the provision of footstools to enable the feet to be supported.

Seating should aim to encourage movement as much as possible. For computer tasks, the chair should be able to be placed close to the edge of the desk so that input devices can be reached and forearm support can be achieved on the desk surface. Children should be encouraged to evaluate their sitting position and take advantage of any adjustability or other supports just as an adult would check rear-view mirror and seat position when sitting in a car.

> Based on the available evidence, it is recommended that seat pan height should allow the child's feet to be flat on the floor. The lack of a backrest is acceptable to encourage movement, but if one is provided it should be adjustable to fit the child's lumbar spine. Armrests should be avoided unless they fit the child and desk well. The seat style should support a range of reasonable postures.

2.2.3. Encourage suitable postures by selecting and adjusting an appropriate work surface

Desks can enable the user to sit in a range of comfortable postures, with enough space for input devices and documents and sufficient depth for positioning the computer display. In school situations the desk may also have to accommodate two or more users simultaneously. Throughout the working day, school computer desks may also have to accommodate children of substantially different sizes. Desks also need to accommodate both computer and paper-based tasks.

The benefits of being able to support the forearms during computer work have been demonstrated for both adult and child populations. Supporting the forearms on the desk surface or on chair armrests has been shown to reduce muscle activity during computer use (Aaras *et al.* 1997, Karlqvist *et al.* 1999, Woods *et al.* 2002, Straker *et al.* 2008d). The use of support also results in reduced discomfort and musculoskeletal symptoms (Bergqvist *et al.* 1995, Aaras *et al.* 1998, Marcus *et al.* 2002, Woods *et al.* 2002, Korhonen *et al.* 2003, Cook and Burgess-Limerick 2004, Rempel *et al.* 2006). In a review of the health consequences of computer work Aaras *et al.* (2000) concluded that supporting the whole forearms was of fundamental importance for reducing muscle load and musculoskeletal pain. It should be noted that studies have not been universal in supporting the efficacy of forearm support. In a study by Cook and Burgess-Limerick (2004), 15% of participants withdrew from the forearm support condition because of discomfort or dissatisfaction with this work position due to large abdomens. Delisle *et al.* (2006b) concluded that forearm support may be beneficial for the neck and shoulder to the detriment of the wrist and forearm. However, the body of evidence seems to strongly support the benefits of the provision of a supporting surface for the forearms. In addition, the efficacy of forearm support during computer use has been specifically shown to be effective for children by Straker *et al.* (2009b). Muscle activity reductions in this study were of a sufficient magnitude to be clinically meaningful.

Forearm support can be provided by moving the keyboard away from the edge of the desk, from chair armrests and from specific support devices that are attached to the chair or desk. Rempel *et al.* (2006) found a reduced incidence of discomfort and pain for call-centre operators who used a forearm support. Cook and Burgess-Limerick (2003) suggested that a curved or shaped work surface may provide the best support. However, forearm support can also be obtained on a straight desk by simply moving the keyboard $\sim$12cm away from the edge of the desk (Marcus *et al.* 2002). It is recommended that a straight desk has the keyboard and mouse positioned far enough away from the front edge of the desk so that the forearms can be supported.

In order to provide forearm support without compromising spinal posture, Cook and Burgess-Limerick (2003) noted a general consensus for the desk height to be at or slightly below the elbow height of the seated operator. While an adjustable height desk may be of benefit to achieve this height initially, it may be feasible and cheaper in school and home settings to manipulate the seated height of the child to suit the desk height, using an adjustable chair or firm cushions (bearing in mind any fire safety regulations) to adjust chair height and a footrest to support the feet when needed.

The desk surface area needs to be large enough to enable forearm support and appropriate keyboard and mouse configuration. The desk needs to be of appropriate depth to permit placement of the display at a sufficient distance to enable visual comfort (see section 1.2.5). There is also nearly always a need for space for documents and other working materials. It is appreciated that schools have limited space and there may be pressure to provide as many workstations as possible. However, insufficient space on the surface of the computer workstation may lead to poor working postures and poor productivity.

One form of 'space-saving' configuration is the use of pull-out keyboard trays or multiple-level desks. These may constrain the available working postures by restricting the potential placements of input devices (Cook and Burgess-Limerick 2003). Computer workstations whereby the mouse and keyboard are at different heights may result in less neutral postures and greater muscle activity (Dennerlein and Johnson 2006b). Pull-out keyboard trays may be a particularly poor choice for younger computer users because their smaller reach would make it difficult to access documents or controls on the desk surface. In addition, if children are required to share a school computer, a keyboard tray may restrict input for one of the users. Keyboard trays and their adjustment mechanisms can also constitute a hazard to the knees or thighs if they are located under the desk surface (Cook and Burgess-Limerick 2003).

Sloped desks have been shown to be effective in bringing children's posture into a more beneficial alignment for written tasks (Marschall *et al.* 1995, Koskelo *et al.* 2007) in accordance with the recommendations of Mandal (1982). However, a sloping desk is not likely to be practical for typical computer-based work as the keyboard, mouse and other materials may slide off the desk. Document holders for hard copy documents and inclined supports for books can reduce head and neck flexion. Positioning paper material close to the computer display can reduce head and neck rotation.

Based on the available evidence, it is recommended that the desk should allow forearm support, be adjusted to about sitting elbow height and be a single thin surface of reasonable size.

2.2.4. Encourage appropriate postures and gaze angle by positioning computer display appropriately

The appropriate positioning of a computer display requires attention to both visual and musculoskeletal concerns, with a combination of spinal posture and eye gaze angle determining how the target is viewed (Aarås *et al.* 1997, Mon-Williams *et al.* 1999, Burgess-Limerick *et al.* 2000, Psihogios *et al.* 2001, Sommerich *et al.* 2001).

Existing guidelines defining display heights for adults generally recommend the top of the viewing area of the display be placed in a range between eye level and 40–60° below eye level (for example, Australian Standard 3590.2; Canadian Can/CSA-Z412-M89; European ISO-9241; ANSI/HFES 100. 2007) (see Straker *et al.* 2009e for review). This broad range of recommendations persists in spite of considerable research, perhaps because of the large intra-individual differences in the relationship of musculoskeletal and visual systems (Burgess-Limerick *et al.* 1998, Mon-Williams *et al.* 1999, Straker and Mekhora 2000). Differences in methods may also contribute to the wide range of recommendations in the literature – for example, it is not always stated whether the viewing angle is measured in relation to the centre or the top of the display.

If the display is placed such that the top of the viewing area of the display is at eye level, the posture of the head and neck will be more upright and cervical erector spinae activity will likely be lower, but this position may be more stressful for the visual system (Jaschinski *et al.* 1998). Lower monitor placements are associated with greater head and neck flexion, which could be considered more stressful on the neck and shoulder muscles with higher muscle activity levels as the consequence (Straker *et al.* 2008a). However, research evidence suggests that this is not generally the case. Epidemiological studies show fewer reports of musculoskeletal discomfort associated with lower display heights (Marcus *et al.* 2002, Fostervold *et al.* 2006) and these lower display angles correspond more closely to visual preferences (viewing angles of 9–10° below the horizontal (Psihogios *et al.* 2001, Sommerich *et al.* 2001)). Trapezius muscle load is an important consideration as it is a large muscle and a common site of discomfort in computer users (Bergqvist *et al.* 1995). Working with head and neck flexion will likely increase cervical erector spinae muscle activity (Villanueva *et al.* 1997, Turville *et al.* 1998, Sommerich *et al.* 2001, Greig *et al.* 2005). However, trapezius activity may be unaffected (Aaras *et al.* 1997, Villanueva *et al.* 1997, Sommerich *et al.* 2001, Fostervold *et al.* 2006) or may even be reduced for lower viewing angles (Turville *et al.* 1998, Greig *et al.* 2005). Trapezius muscle activity has been shown to be relatively constant across a range of viewing angles in both adults (Turville *et al.* 1998, Fostervold *et al.* 2006, Straker *et al.* 2009e) and children (Straker *et al.* 2008a). Gaze angles above the horizontal (the top of the viewing area of the display positioned above eye level) may increase strain on deep subcapital muscles (Straker *et al.* 2009e) but have been, rarely, recommended. The practice of placing the computer display on top of the central processing unit is not recommended. This workstation configuration has been observed in school settings in several countries (Noro *et al.* 1997, Szeto 2003, Straker *et al.* 2008a) and is likely to promote an upward gaze angle and unwanted increases in muscle activity, particularly in smaller children.

In summary, evidence relating to viewing angles generally supports display positions that promote a downward gaze angle. In accordance with this, Cook and Burgess-Limerick (2003) recommend that workstations should permit adjustment of display height so that downward viewing angles between 0° and 45° are possible. However, there appears to be no specific angle within this range that has particularly advantages (Burgess-Limerick *et al.* 1998). Marked inter-individual variability in gaze angle preference (Burgess-Limerick *et al.* 1998) and the interaction of musculoskeletal and visual systems (Mon-Williams *et al.* 1999) exists.

Given the similarity of responses to changes in display height between adults and children (see Straker *et al.* 2008a,b, 2009e, Maslen and Straker 2009), it seems reasonable that similar display placement recommendations may be appropriate for children. It is recommended that children start with the top of the display at sitting eye height and be able to adjust this lower if required for comfort.

The appropriate distance to the computer display depends on age, visual capacity, viewing angle (the display can be placed closer if it is lower) and the clarity and size of the image or text (Cook and Burgess-Limerick 2003, Rempel *et al.* 2007b). Preferred viewing distances, measured from the eye to the centre of the computer display, range between 50 and 100 cm (Jaschinski *et al.* 1998, Delleman and Berndsen 2002, Shieh and Lee 2007) for adults. No studies could be found that have investigated optimal viewing distances for children. It is recommended that the display is positioned at approximately arm's length as a 'user-friendly' starting point, which can be modified by children themselves to comfort.

Neck or head rotation away from the midline has been linked to increased discomfort or musculoskeletal symptoms among computer users (van den Heuvel *et al.* 2006, Szeto and Sham 2008). For adults, if the computer display is the primary visual target, it should be positioned directly in front of the user (Cook and Burgess-Limerick 2003). In situations where children share a single computer it is obviously not possible to place the display directly in front of all children. In this situation it is of particular importance that the computer display is placed at a greater viewing distance, as a near display will create more extreme viewing angles for those not directly in front of the screen. Exchanging places among the users during long computer use sessions may also provide some protection against discomfort. For single child use it is recommended that the display be positioned directly in front.

Lighting and glare can be sources of visual discomfort during computer use. Placing the computer display perpendicular to windows, using indirect lighting sources, window treatments and anti-glare screens can all be used to limit glare (Cook and Burgess-Limerick 2003, Anshel 2007), although mesh anti-glare screens are not recommended (Anshel 2007). An association between fewer reports of discomfort and reporting that the display was free from glare was found in a study of home computer use by children (Jacobs *et al.* 2006). It is recommended that children be taught to identify glare and adjust their workstation to avoid it.

The display technology may influence clarity, stability and adjustability of the display. Older style cathode ray tube displays are currently being replaced in many adult and child workstations with thin film transistor (or LCD) displays. These thinner and lighter weight displays provide for greater flexibility of positioning and may have a clearer, more stable image. It is recommended that a good quality display with good contrast be used and be free of flicker.

> Based on the available evidence, it is recommended that computer displays should be placed so that the top of the display is at or below eye height, at about arm's length away and directly in front of the user. Workstation orientation should minimise glare. A good quality display with a clear stable image should be used.

2.2.5. *Encourage appropriate postures by selecting and positioning keyboard and pointing device appropriately*

The keyboard and mouse are currently the most common computer input devices; however, other pointing devices, such as touchpads, trackballs, joysticks, and optical pens are used (Woods *et al.* 2002, Cook and Burgess-Limerick 2003). Only limited data are available characterising the usage of different input devices by children, but the mouse appears to be the most common pointing device used by children both at home (Burke and Peper 2002) and at school (Sotoyama *et al.* 2002).

Research has shown that young children can learn to use a mouse easily (see review by Barrero and Hedge 2002, Donker and Reitsma 2007). However, mouse use has been associated with pain in schoolchildren (Breen *et al.* 2007), as it has in adults (Jensen *et al.* 2002), so it is important to optimise the size, button activation force and location of the mouse on the desk.

There is only limited research evaluating mouse size and children's anthropometry. An interesting study by Blackstone *et al.* (2008) compared the use of input devices by 14 children aged 5–8 years and their same-sex biological parent. Subjects used standard and smaller-sized keyboards and mice. When using the standard mouse the children had 18° more ulnar deviation and 9° less wrist extension than their parents. They also had twice as large a range of motion in both wrist flexion/extension and ulnar/radial deviation. Children had to reach around the keyboard to access the mouse and access the mouse buttons from the side rather than from the top of the mouse because it was too big for their hands. When children used the smaller mouse, there was a significant reduction in ulnar deviation and a decrease in muscle activity. Better performance (fewer errors and faster movement times) was also associated with the smaller mouse. Children had to use proportionally more force than adults to operate the mouse buttons and these authors recommended that both the mouse button activation force and the physical size of input devices be designed for children. It is recommended that mouse size be appropriate to the child's hand size.

Due to a lack of research, no recommendations can be made regarding the necessity of providing a mouse specifically shaped for left-handers. While it appears that most adults can adapt to right-handed mouse use (Woods *et al.* 2002), it cannot be assumed that this is the case for all left-handed individuals, including children. It is recommended that a symmetrical mouse be used as this would permit the greatest flexibility in a situation where multiple users are required to use the same computer. A study of computer use by British adults revealed that even left-handed adults tended to use the mouse with their right hand (Woods *et al.* 2002). It is unknown whether this also applies to children; hence, it is recommended that workstations enable mouse use on either side of the keyboard.

An extension of this flexibility arises from research conducted by Delisle *et al.* (2004), in line with principles proposed initially by Cook and Kothiyal

(1998). Right-handed, adult computer users were trained to use a mouse with their left hand. A total of 16 of the 27 participants fully converted to left-handed mouse use within 1 month. Posture was significantly improved when using the mouse with the left hand, as right-handed use required greater deviation of the upper limb in order to bypass the number pad on the right side of the keyboard. Recommendations that a keyboard without number pad is used when practical have been put forward by a number of authors, as discussed in the following paragraphs. However if this is not practical, left-handed mouse use might constitute an effective alternative. Young children may be particularly adaptable in this regard.

A panel of 21 'experts' assessed several non-keyboard input devices for adult use in a study by Woods *et al.* (2002). There were wide individual differences in preference, although the traditional mouse was the most favoured overall. The shape of the device was important for comfort, which suggests that smaller devices may be more appropriate for young children, in line with the results of Blackstone *et al.* (2008). Operation of some trackballs was difficult because the ball was too large for the adult users and it was reported that the fingers had to be held above the trackball in order to prevent accidental activation. In line with this report, and given the importance of forearm support as discussed in section 1.2.3, the trackball in its current form may generally not be a good choice for children.

There is little evidence that alternate keyboard styles (split, inclined, different shape) generally provide significant benefits to adult computer users in comparison to standard keyboards in the workplace (Cook and Burgess-Limerick 2003, Rempel *et al.* 2007a). Although recent laboratory studies have shown no performance decrement and improved fatigue and posture measures in adults (McLoone *et al.* 2009). A review of workplace interventions by Brewer *et al.* (2006) reported mixed evidence for the effects of alternative keyboards on musculoskeletal outcomes. It is likely that some keyboards may be more appropriate for particular adults but the effect may be small. There is very limited research addressing appropriate keyboard designs for children. In the study by Blackstone *et al.* (2008) described earlier, there were no systematic differences in physical exposure measures between the standard and smaller keyboards, and only negligible differences in performance. However, the difference in keyboard size was only marginal, as more proportionally scaled-down keyboards could not be found at the time of the study. As per mouse use, the relative activation force required for key activation by children was twice that of their parents. It is recommended that a scaled-down keyboard be provided for younger children, with small key activation forces.

Blackstone *et al.*'s (2008) study also highlighted the ulnar deviation that was required by young children in order to access a mouse placed to the side of a standard keyboard. Reduced muscle activity and more neutral postures have been reported when a mouse was used in conjunction with a keyboard without a number pad (Cook and Kothiyal 1998, Sommerich *et al.* 2002). A review of musculoskeletal consequences of keyboard use by Gerr *et al.* (2006) also concluded that minimising ulnar deviation may reduce the risk to the musculoskeletal system. Using a keyboard without a number pad may therefore be particularly appropriate for children, with their smaller size and reach. It is recommended that keyboards without a number pad be used where possible, permitting a closer position of the mouse to the midline of the body.

Negative slope keyboards have been recommended in order to reduce wrist extension (Hedge and Powers 1995) and have been concurrent with improved postural (RULA) scores in children (Laeser *et al.* 1998). However, the effects of the negative slope keyboard in the latter study cannot be extracted from the alteration of the workstation to suit the child's anthropometry, and the change in mouse location, so there is not yet any definite evidence that tilt-down keyboards can be of benefit for children. Further, a specialised tilt-down keyboard tray has other limitations (see desk section above) and therefore this is not recommended. From adult studies one can infer, however, that minimising keyboard thickness, having the keyboard placed at or below elbow height and supporting the forearms during keyboard and mouse use are all beneficial for the musculoskeletal system (Faucett and Rempel 1994, Aaras *et al.* 1997, Marcus *et al.* 2002, Woods *et al.* 2002, Cook and Burgess-Limerick 2003, Gerr *et al.* 2006). A thin keyboard with minimal slope and a clear key activation feel is recommended. Compared to flat keyboards, keyboards with a positive slope have been shown to increase wrist extension (Simoneau *et al.* 2003) and it is likely that the new thin keyboards, due to their thickness being more in proportion to the stature of the smaller children, will reduce wrist extension.

In summary, research relating specifically to children's use of input devices is notable by its scarcity and the principles that apply to adults have often had to be extrapolated to children to provide any evidence.

> Based on the available evidence, it is recommended that input devices be placed on the desk surface, with the keyboard straight in front of the user, but away from the desk edge in order to take advantage of forearm support. The mouse should be placed close to

> the keyboard and sufficient room should be available for operation of the mouse. The mouse should be symmetrical in shape. A thin keyboard, preferably without numeric pad, should be used. Scaled-down versions of input devices are recommended for younger children.

2.3. *Encourage appropriate behaviour when using and transporting notebook computers*

The last three guidelines deal with additional issues: laptop/notebook computer use, touch-typing skill and early recognition of discomfort.

The mandatory notebook programs implemented by some schools may have significant ramifications for children's musculoskeletal well-being, entailing risk associated with not only notebook use, but also the burden carrying the notebook computers to and from school. However, the perceived need for children to have notebook computers to use at school and home is now diminished, given home computer and Internet access. This enables children to share files at school and home without the need to transport expensive computer equipment.

In a study of Australian students aged 10–17 years, 61% of children in such programmes experienced discomfort carrying their notebooks. The type of notebook was related to the discomfort, with least discomfort associated with the lightest model. Similarly, Heasman *et al.* (2000) found an association between weight of a portable computer and musculoskeletal discomfort in adults. In a study of US children, musculoskeletal discomfort in several body regions was also associated with notebook carriage (Sommerich *et al.* 2007) and there was a trend for discomfort to be related to the mode of transport (bearing the load with one shoulder). In contrast, the method of transportation in adults (Heasman *et al.* 2000) was reported to be unrelated to the discomfort experienced in any body region. It had been expected that carrying the notebook in a backpack, rather than using a shoulder strap, carrying handle or carrying in a briefcase, would be associated with less discomfort. It seems wise to err on the side of caution where children are concerned, however, and to follow the recommendation by Harris and Straker (2000). It is recommended that a comfortable backpack with two shoulder straps should be used to transport the notebook. In addition, the weight of the notebook should be kept to a minimum. Recent evidence has highlighted that backpacks should not be perceived as heavy and fatiguing by children and that walking and cycling to school may be protective (Haselgrove *et al.* 2008).

Optimisation of posture while using a notebook or similar sized computer is also important, in accordance with the principles governing display position and forearm support described earlier in this paper. Poorer postures, increased muscle activity, shorter viewing distances and greater discomfort have all been associated with the use of notebook computers in comparison to desktop computers in adults (Saito *et al.* 1997, Straker *et al.* 1997, Harris and Straker 2000, Szeto and Lee 2002). Use of a notebook computer was associated with more static postures in adults (Sommerich *et al.* 2002) in comparison to operating the notebook with an external keyboard and mouse. Improved neck posture and comfort were also evident when the external devices were used with the notebook. Other authors similarly recommend the use of external input devices and display screens when using small, mobile computers (Harris and Straker 2000, Heasman *et al.* 2000, Berkhout *et al.* 2004). When using computers with fixed articulation between keyboard and screen, it may not be possible to optimise both keyboard access and distance to the display (Straker *et al.* 1997). Older children are likely to experience the same problems when using notebook computers as adults and are therefore likely to need an external keyboard. However, smaller children may be able to adopt reasonable postures, including forearm support and appropriate viewing angle. It is recommended that an external keyboard be provided when a child cannot adopt an appropriate posture with a notebook computer. Interestingly, tablet-style notebooks have been found to result in postures and muscle activities more similar to writing with pen and paper (Straker *et al.* 2009a). A further issue with notebook computers is the use away from desks. Harris and Straker (2000) found that children reported using notebooks on desks only 34% of the time. Other postures included lying prone, floor sitting and sitting with computer on lap. The portability provides the opportunity for posture variety, but also for more extreme postures and glare problems. It is recommended that children are encouraged to use a range of reasonable postures, but are taught to avoid extreme postures and be aware of glare.

> Based on the available evidence, it is recommended that, if required, notebook computers should be lightweight and carried in a two-strap back pack. External keyboard and display height adjustment is likely to be required for larger children. Alternatives to chair sitting postures should be encouraged as long as they are reasonable postures.

2.4. *Teach children computing skills*

According to Delleman and Berndsen (2002), being able to touch-type offers the advantage that display height and keyboard position can be optimised independently. Given the documented benefits of forearm support and the effects of display height and viewing distance on posture and muscle activity (see sections 1.2.3 and 1.2.4), this scenario may help to reduce musculoskeletal load. A trend for muscle activity to be lower for touch-typists (Sommerich *et al.* 2001) offers further support for the benefits of touch-typing. Limited evidence relates specifically to children; there was a trend for less musculoskeletal discomfort in US children aged 12–13 years who could touch-type (Jacobs and Baker 2002). It could not be determined whether this protective effect was related to the adoption of better posture or that children who could touch-type finished the task more quickly. However, either mechanism is likely to be beneficial.

Postural variability was found to be reduced in adult touch-typists in a study by Straker *et al.* (2009c). However, further analysis revealed that the less static postures associated with non-touch-typists were actually still highly stereotypical, resulting from the alternation of two head postures, which corresponded to looking at the screen and viewing the keyboard. This apparently greater variability, therefore, may not prove to be an advantage, given the more flexed head position that is associated with viewing the keyboard and the benefits of touch-typing described above.

Szeto *et al.* (2005) reported more erratic key-striking forces in symptomatic office workers. Therefore, children should be taught to use minimal force. Children should also be taught keyboard shortcuts to provide alternatives to mouse use and thus greater variety.

Based on the available evidence, it is recommended that children should be taught to touch-type with minimal force, to use keyboard shortcuts and be skilled in software use.

2.5. Teach children to respond to discomfort

The uptake of computer use by children is a relatively recent phenomenon and longitudinal studies of the tracking into adulthood of postures and loads caused by computer use have therefore not been undertaken. According to Woods *et al.* (2002), however, there are indications that back, neck and shoulder pain in adolescence and childhood are risk factors for the development of MSDs in adulthood. Children are starting to use computers at a very young age (Rideout *et al.* 2003, Straker *et al.* 2006d). Duration of computer use can be extensive, particularly for children attending schools with mandatory notebook computer programs (Harris and Straker 2000, Sommerich *et al.* 2007). The effects of this computer use at a time when children are growing rapidly and developing spinal postures are now starting to manifest themselves in the population, with reports of musculoskeletal discomfort in children being commonplace (Harris and Straker 2000, Jacobs and Baker 2002, Williams 2002, Szeto 2003, Hakala *et al.* 2006, Straker *et al.* 2006d). Of great concern is the recent research that demonstrates that computer use by adolescents is related to their habitual sitting posture (Straker *et al.* 2006c).

The American Optometric Association (undated) states that a number of characteristics make children particularly susceptible to negative visual consequences of computer use. With limited self-awareness, children may fail to respond to discomfort because of their absorption in the task. They may also ignore symptoms that would be addressed by adults because they think that everyone else sees the same way they do. These childhood attributes are equally relevant to musculoskeletal discomfort and workstation set-up. More than a quarter of the students in the study of Harris and Straker (2000) reported that they would continue with the computer task if they were experiencing discomfort, with another 18% saying that they would 'not think about it'.

Based on the available evidence, it is recommended that children should be taught to be aware of discomfort and be given strategies to prevent it. Adult assistance and the seeking of health professional advice are also recommended if symptoms persist, to avoid development of a disabling disorder.

3. Summary

Computer use by children is extensive and there have been widespread concerns about the possible impacts of this on health. This paper has reviewed the evidence regarding the physical aspects of child–computer interaction and provided recommendations for wise use of computers. Subsequent detailed guidelines are required, which review the evidence with regard to the cognitive and social aspects of this interaction.

Implementation of these guidelines should be trialled, with the efficacy assessed by randomised and controlled trials. It is anticipated that implementation within schools will be relatively easy to achieve for many guidelines, with home implementation relying more on individual family knowledge and motivation.

Aspects of these guidelines could be taught to children by the various adults responsible for their welfare and with an interest in children using computers wisely. Thus, parents and teachers, ergonomists and health professionals, software and hardware designers and suppliers all have a role in ensuring that children are able to use computers wisely.

References

Aarås, A., Horgen, G., and Ro, O., 2000. Work with the visual display unit: health consequences. *International Journal of Human-Computer Interaction*, 12, 107–134.

Aarås, A., *et al.*, 1997. Postural load during VDU work: A comparison between various work postures. *Ergonomics*, 40, 1255–1268.

Aarås, A., *et al.*, 1998. Musculoskeletal, visual and psychosocial stress in VDU operators before and after multidisciplinary ergonomic interventions. *Applied Ergonomics*, 29, 335–354.

American Optometric Association, undated. *Impact of computer use on children's vision* [online]. Available from: www.aoa.org/x5379.xml [Accessed 31 March 2008].

Anshel, J., 2007. Visual ergonomics in the workplace. *American Association of Occupational Health Nurses Journal*, 55, 414–420.

Attewell, P., Suazo-Garcia, B., and Battle, J., 2003. Computers and young children: Social benefit or social problem? *Social Forces*, 82, 277–296.

Balci, R. and Aghazadeh, F., 2004. Effects of exercise breaks on performance, muscular load and perceived discomfort in data entry and cognitive tasks. *Computers and Industrial Engineering*, 46, 399–411.

Barrero, M. and Hedge, A., 2002. Computer environments for children: A review of design issues. *Work*, 18, 227–237.

Bennett, C.L., 2002. Computers in the elementary school classroom. *Work*, 18, 281–285.

Bergqvist, U., *et al.*, 1995. Musculoskeletal disorders among visual display terminal workers: individual, ergonomic and work organizational factors. *Ergonomics*, 38, 763–776.

Berkhout, A.L., Hendriksson-Larsén, K., and Bongers, P., 2004. The effect of using a laptop station compared to using a standard laptop PC on the cervical spine torque, perceived strain and productivity. *Applied Ergonomics*, 35, 147–152.

Bernard, B.P., 1997. *Musculoskeletal disorders and workplace factors* [online]. NIOSH Publication number 97–141. Available from: http://www.cdc.gov/niosh/docs/97–141/ [Accessed 5 June 2008].

Blackstone, J.M., *et al.*, 2008. Physical exposure differences between children and adults when using standard and small computer input devices. *Ergonomics*, 51, 872–889.

Blangsted, A.K., *et al.*, 2004. The effect of physical and psychosocial loads on the trapezius muscle activity during computer keying tasks and rest periods. *European Journal of Applied Physiology*, 91, 253–258.

Blatter, B.M. and Bongers, P.M., 2002. Duration of computer use and mouse use in relation to musculoskeletal disorders of neck or upper limb. *International Journal of Industrial Ergonomics*, 30, 295–306.

Bonis, J., 2007. Acute Wiitis. *New England Journal of Medicine*, 356, 2431.

Boucsein, W. and Thum, M., 1995. Recovery from strain under different work-rest schedules. *In*: *Proceedings of the Human Factors and Ergonomics Society 39th annual meeting*, Santa Monica, CA: Human Factors and Ergonomics Society, 785–788.

Breen, R., *et al.*, 2007. An investigation of children's posture and discomfort during computer use. *Ergonomics*, 50, 1582–1592.

Brewer, S., *et al.*, 2006. Workplace interventions to prevent musculoskeletal and visual symptoms and disorders among computer users: A systematic review. *Journal of Occupational Rehabilitation*, 16, 325–358.

Burgess-Limerick, R., Mon-Williams, M., and Coppard, V.L., 2000. Visual display height. *Human Factors*, 42, 140–150.

Burgess-Limerick, R., Plooy, A., and Ankrum, D.R., 1998. The effect of self-selected computer monitor height on posture and gaze angle. *Clinical Biomechanics*, 13, 584–592.

Burke, A. and Peper, E., 2002. Cumulative Trauma Disorder risk for children using computer products: results of a pilot investigation with a student convenience sample. *Public Health Reports*, 117, 350–357.

Burke, V., *et al.*, 2006. Television, computer use, physical activity, diet and fatness in Australian adolescents. *International Journal of Pediatric Obesity*, 1, 248–255.

Callaghan, J.P. and McGill, S.M., 2001. Low back joint loading and kinematics during standing and unsupported sitting. *Ergonomics*, 44, 280–294.

Cardon, G., *et al.*, 2004. Sitting habits in elementary schoolchildren: a traditional versus a 'Moving School'. *Patient Education and Counselling*, 54, 133–142.

Chang, C.-H., *et al.*, 2007. Daily computer usage correlated with undergraduate students' musculoskeletal symptoms. *American Journal of Industrial Medicine*, 50, 481–488.

Chung, J.W.Y. and Wong, T.K.S., 2007. Anthropometric evaluation for primary school furniture design. *Ergonomics*, 50, 323–334.

Ciccarelli, M., *et al.*, 2006. *ITKids: does computer use reduce postural variation in children?* [online]. Available from: http://www.iea.cc/ergonomics4children/pdfs/art0231.pdf [Accessed 19 May 2008].

Cirarelli, M., *et al.*, 2009. ITKids: How children's postural variation differs from adults when using different information and communication technologies. *In*: *Proceedings of the 17th World Congress on Ergonomics*, 9–14 August, Beijing, China. Hsinchu, Taiwan: International Ergonomics Association.

Colombini, D., *et al.*, 1986. Biomechanical, electromyographic and radiological study of seated postures. *In*: E.N. Corlett, J.R. Wilson, and I. Manenica, eds. *The ergonomics of working postures*. London: Taylor and Francis, 331–334.

Cook, C. and Burgess-Limerick, R., 2003. Guidelines for computer workstations. *Ergonomics Australia*, 17, 19–37.

Cook, C. and Burgess-Limerick, R., 2004. The effect of forearm support on musculoskeletal discomfort during call centre work. *Applied Ergonomics*, 35, 337–342.

Cook, C. and Kothiyal, K., 1998. Influence of mouse position on muscular activity in the neck, shoulder and arm in computer users. *Applied Ergonomics*, 29, 439–443.

Corlett, E.N., 2006. Background to sitting at work: research-based requirements for the design of work seats. *Ergonomics*, 49, 1538–1546.

Delisle, A., *et al.*, 2004. Left-handed versus right-handed computer mouse use: effect on upper-extremity posture. *Applied Ergonomics*, 35, 21–28.

Delisle, A., *et al.*, 2006a. Comparison of three computer office workstations offering forearm support: impact on upper limb posture and muscle activation. *Ergonomics*, 49, 139–160.

Delisle, A., *et al.*, 2006b. *Musculoskeletal disorders and computer work: the impact of workstation layout on posture and muscle load of the upper limbs* [online]. Studies and Research Projects/Report R-445. Montréal: IRSST. Available from: http://www.irsst.qc.ca/en/_publicationirsst_100177.html [Accessed 20 May 2008].

Delleman, N.J. and Berndsen, M.B., 2002. Touch-typing VDU operation: workstation adjustment, working posture and workers' perceptions. *Ergonomics*, 45, 514–535.

Dennerlein, J.T. and Johnson, P.W., 2006a. Changes in upper extremity biomechanics across different mouse positions in a computer workstation. *Ergonomics*, 49, 1456–1469.

Dennerlein, J.T. and Johnson, P.W., 2006b. Different computer tasks affect the exposure of the upper extremity to biomechanical risk factors. *Ergonomics*, 49, 45–61.

Dockrell, S., *et al.*, 2007. School children's use of computers and teachers' education in computer ergonomics. *Ergonomics*, 50, 1657–1667.

Donker, A. and Reitsma, P., 2007. Young children's ability to use a computer mouse. *Computers and Education*, 48, 602–617.

European Agency for Health and Safety at Work, 2005. *Expert forecast on emerging physical risks related to occupational safety and health*. Luxembourg: Office for Official Publications of the European Communities.

Faucett, J. and Rempel, D., 1994. VDT-related musculoskeletal symptoms: interactions between work posture and psychosocial work factors. *American Journal of Industrial Medicine*, 26, 597–912.

Fernström, E. and Ericson, M.O., 1997. Computer mouse or trackpoint – effects on muscular load and operator experience. *Applied Ergonomics*, 28, 347–354.

Floru, R., Cail, F., and Elias, R., 1985. Psychophysical changes during a VDU repetitive task. *Ergonomics*, 28, 1455–1468.

Foehr, U., 2006. *Media multitasking among American youth: prevalence, predictors and pairings*. Menlo Park, USA: Kaiser Family Foundation.

Fostervold, K.I., Aaras, A., and Lie, I., 2006. Work with visual display units: long-term health effects of high and downward line-of-sight in ordinary office environments. *International Journal of Industrial Ergonomics*, 36, 331–343.

Galinsky, T., *et al.*, 2007. Supplementary breaks and stretching exercises for data entry operators: a follow-up field study. *American Journal of Industrial Medicine*, 50, 519–527.

Gao, C., *et al.*, 1990. The effects of VDT data entry work on operators. *Ergonomics*, 33, 917–924.

Garcia-Acosta, G. and Lange-Morales, K., 2007. Definition of sizes for the design of school furniture for Bogotá schools based on anthropometric criteria. *Ergonomics*, 50, 1626–1642.

Geldhof, E., *et al.*, 2007. Classroom postures of 8–12 year old children. *Ergonomics*, 50, 1571–1581.

Gerr, F., Monteilh, C.P., and Marcus, M., 2006. Keyboard use and musculoskeletal outcomes among computer users. *Journal of Occupational Rehabilitation*, 16, 265–277.

Gillespie, R.M., *et al.*, 2006. *Musculoskeletal impact of computer and electronic game use on children and adolescents* [online]. Available from: www.iea.cc/ergonomics4children/pdfs/art0235.pdf [Accessed 20 February 2008].

Gouvali, M.K. and Boudolos, K., 2006. Match between school furniture dimensions and children's anthropometry. *Applied Ergonomics*, 37, 765–773.

Graves, L., *et al.*, 2007. Comparison of energy expenditure in adolescents when playing new generation and sedentary computer games: cross sectional study. *British Medical Journal*, 335, 1282–1284.

Greig, A., Straker, L., and Briggs, A., 2005. Cervical erector spinae and upper trapezius muscle activity in children using different information technologies. *Physiotherapy*, 91, 119–126.

Hagberg, M. and Sundelin, G., 1986. Discomfort and load on the upper trapezius muscle when operating a word processor. *Ergonomics*, 29, 1637–1645.

Hagg, G.M. and Aström, A., 1997. Load pattern and pressure pain threshold in the upper trapezius muscle and psychosocial factors in medical secretaries with and without shoulder/neck disorders. *International Archives of Occupational and Environmental Health*, 69, 423–432.

Hakala, P.T., *et al.*, 2006. Frequent computer-related activities increase the risk of neck-shoulder and low back pain in adolescents. *European Journal of Public Health*, 16, 536–541.

Harris, C. and Straker, L., 2000. Survey of physical ergonomics issues associated with school children's use of laptop computers. *International Journal of Industrial Ergonomics*, 26, 337–347.

Harris, C., Straker, L., and Pollock, C., submitted. The influence of age, gender and other information technology use on young people's computer use at school and home. *Work*, under review.

Haselgrove, C., *et al.*, 2008. Perceived school bag load, duration of carriage, and method of transport to school are associated with back and neck pain in adolescents: An observational study. *Australian Journal of Physiotherapy*, 54, 193–200.

Heasman, T., Brooks, A., and Stewart, T., 2000. *Health and safety of portable display screen equipment*. Contract Research Report 304/2000. London: Health and Safety Executive.

Hedge, A. and Powers, J.R., 1995. Wrist posture while keyboarding: effects of a negative slope keyboard support system and full motion forearm supports. *Ergonomics*, 38, 508–517.

Ho, S. and Lee, T., 2001. Computer usage and its relationship with adolescent lifestyle in Hong Kong. *Journal of Adolescent Health*, 29, 258–266.

Ijmker, S., *et al.*, 2007. Should office workers spend fewer hours at their computer? A systematic review of the literature. *Occupational and Environmental Medicine*, 64, 211–222.

Jacobs, K. and Baker, N.A., 2002. The association between children's computer use and musculoskeletal discomfort. *Work*, 18, 221–226.

Jacobs, K., Hudak, S., and McGiffert, J., 2006. *Musculoskeletal complaints by middle school students with computer use* [online]. Available from: www.iea.cc/ergonomics4children/pdfs/art0210.pdf [Accessed 20 February 2008].

Janssen, I., *et al.*, 2005. Comparison of overweight and obesity prevalence in school-aged youth from 34 countries and their relationships with physical activity and dietary patterns. *Obesity Reviews*, 6, 123–132.

Jaschinski, W., Heuer, H., and Kylian, H., 1998. Preferred position of visual displays relative to the eyes: a field study of visual strain and individual differences. *Ergonomics*, 41, 1034–1049.

Jensen, C., *et al.*, 1993. Trapezius muscle load as a risk indicator for occupational shoulder-neck complaints. *International Archives Occupational and Environmental Health*, 64, 415–423.

Jensen, C., *et al.*, 2002. Musculoskeletal symptoms and duration of computer and mouse use. *International Journal of Industrial Ergonomics*, 30, 265–275.

Johnson, P. and Blackstone, J.M., 2007. Kids and gender: differences in exposure and how anthropometric differences could be incorporated computer input device design. *Scandinavian Journal of Work, Environment and Health*, (Suppl. 3), 26–32.

Johnson, P., *et al.*, 2000. Exposure assessment: measuring and characterizing force exposure during computer mouse use. *Scandinavian Journal of Work, Environment and Health*, 26 (5), 398–406.

Karlqvist, L.K., *et al.*, 1999. Computer mouse and track-ball operation: similarities and perceived differences in posture, muscular load and perceived exertion. *International Journal of Industrial Ergonomics*, 23, 157–169.

Kautiainen, S., *et al.*, 2005. Use of information and communication technology and prevalence of overweight and obesity among adolescents. *International Journal of Obesity*, 29, 925–933.

Kelly, G., Dockrell, S., and Galvin, R., 2009. Computer use in school: its effect on posture and discomfort in schoolchildren. *Work*, 32, 321–328.

Kent, N. and Facer, K., 2004. Different worlds? A comparison of young people's home and school ICT use. *Journal of Computer Assisted Learning*, 20, 440–455.

Kopardekar, P. and Mital, A., 1994. The effect of different work-rest schedules on fatigue and performance of a simulated directory assistance operator's task. *Ergonomics*, 37, 1697–1707.

Korhonen, T., *et al.*, 2003. Work related and individual predictors for incident neck pain among office employees working with video display units. *Occupational and Environmental Medicine*, 60, 475–482.

Koskelo, R., Vuorikari, K., and Hanninen, O., 2007. Sitting and standing postures are corrected by adjustable furniture with lowered muscle tension in high-school students. *Ergonomics*, 50, 1643–1656.

Laeser, K.L., Maxwell, L.E., and Hedge, A., 1998. The effect of computer workstation design on student posture. *Journal of Research on Computing in Education*, 31, 173–188.

Lajunen, H.-R., *et al.*, 2007. Are computer and cell phone use associated with body mass index and overweight? A population study among twin adolescents. *BMC Public Health*, 7, 24–31.

Lanningham-Foster, L., *et al.*, 2006. Energy expenditure of sedentary screen time compared with active screen time for children. *Pediatrics*, 118, 1831–1835.

Legg, S.J., *et al.*, 2003. Mismatch between classroom furniture dimensions and student anthropometric characteristics in three New Zealand secondary schools. *In*: *Proceedings of the 15th congress of the International Ergonomics Association, Ergonomics for children in educational environments symposium*, vol. 6, Seoul, Korea. Hsinchu, Taiwan: International Ergonomics Association, 395–397.

Levine, J.A. and Miller, J.M., 2007. The energy expenditure of using a 'walk-and-work' desk for office workers and obesity. *British Journal of Sports Medicine*, 41, 558–561.

Linton, S.J., *et al.*, 1994. The effects of ergonomically designed school furniture on pupils' attitudes, symptoms and behaviour. *Applied Ergonomics*, 25, 299–304.

McLoone, H.E., *et al.*, 2009. Design and evaluation of a curved computer keyboard. *Ergonomics*, 52, 1529–1539.

Maddison, R., *et al.*, 2007. Energy expended playing video console games: an opportunity to increase children's physical activity? *Pediatric Exercise Science*, 19, 1–24.

Mandal, A.C., 1982. The correct height of school furniture. *Human Factors*, 24, 257–269.

Marcus, M., *et al.*, 2002. A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders. *American Journal of Industrial Medicine*, 41, 236–249.

Marschall, M., Harrington, A., and Steele, J., 1995. Effect of workstation design on sitting posture in young children. *Ergonomics*, 38, 1932–1940.

Maslen, B. and Straker, L., 2009. A comparison of posture and muscle activity means and variation amongst young children, older children and young adults whilst working with computers. *Work*, 32, 311–320.

Mathiassen, S.E., 2006. Diversity and variation in biomechanical exposure: What is it and why would we like to know? *Applied Ergonomics*, 37, 419–427.

Mekhora, K., *et al.*, 2000. The effect of ergonomic intervention on discomfort in computer users with tension neck syndrome. *International Journal of Industrial Ergonomics*, 26, 367–379.

Milanese, S. and Grimmer, K., 2004. School furniture and the user population: an anthropometric perspective. *Ergonomics*, 47, 416–426.

Molenbroek, J.F.M., Kroon-Ramaekers, Y.M.T., and Snijders, C.J., 2003. Revision of the design of a standard for the dimensions of school furniture. *Ergonomics*, 46, 681–694.

Mon-Williams, M., *et al.*, 1999. Vertical gaze direction and postural adjustment: An extension of the Heuer model. *Journal of Experimental Psychology: Applied*, 5, 35–53.

Murphy, S., Buckle, P., and Stubbs, D., 2004. Classroom posture and self-reported back and neck pain in schoolchildren. *Applied Ergonomics*, 35, 113–120.

Murphy, S., Buckle, P., and Stubbs, D., 2007. A cross-sectional study of self-reported back and neck pain among English schoolchildren and associated physical and psychological risk factors. *Applied Ergonomics*, 38, 797–804.

Mutunga, M., *et al.*, 2006. Socioeconomic differences in biological and behavioural risk factors for obesity in a representative sample of adolescents from Northern Ireland. *International Journal of Pediatric Obesity*, 1, 114–119.

Nag, P.K., *et al.*, 2008. Human-seat interface analysis of upper and lower body weight distribution. *International Journal of Industrial Ergonomics*, 38, 539–545.

Noro, K., Okamoto, T., and Kojima, M., 1997. *Computer operation by primary school children in Japan – present conditions and issues* [online]. Available from: http://cehd.umn.edu/kls/ecee/pdfs/primschoolinjapan.pdf [Accessed 9 June 2008].

Oates, S., Evans, G.W., and Hedge, A., 1998. An anthropometric and postural risk assessment of children's school computer work environments. *Computers in the Schools*, 14, 55–63.

Olds, T., *et al.*, 2004. *Children and sport: A report prepared for the Australian Sports Commission* [online]. Available from: http://www.ausport.gov.au/__data/assets/file/0018/115344/childrenpt1exec.rtf [Accessed 1 May 2008].

Panagiotopoulou, G., *et al.*, 2004. Classroom furniture dimensions and anthropometric measures in primary school. *Applied Ergonomics*, 35, 121–128.

Parcells, C., Stommel, M., and Hubbard, R., 1999. Mismatch of classroom furniture and student body dimensions. *Journal of Adolescent Health*, 24, 265–273.

Pheasant, S., 1996. *Bodyspace*. London: Taylor and Francis.

Psihogios, J.P., *et al.*, 2001. A field evaluation of monitor placement effects in VDT users. *Applied Ergonomics*, 32, 313–325.

Rempel, D.M., *et al.*, 2006. A randomised controlled trial evaluating the effects of two workstation interventions on upper body pain and incident musculoskeletal disorders among computer operators. *Occupational and Environmental Medicine*, 63, 300–306.

Rempel, D., *et al.*, 2007a. The effect of six keyboard designs on wrist and forearm postures. *Applied Ergonomics*, 38, 293–298.

Rempel, D.M., *et al.*, 2007b. The effects of visual display distance on eye accommodation, head posture, and vision and neck symptoms. *Human Factors*, 49, 830–838.

Rideout, V.J., Vandewater, E.A., and Wartella, E.A., 2003. *Zero to six: electronic media in the lives of infants, toddlers and preschoolers*. Menlo Park, USA: Kaiser Family Foundation.

Roberts, D.F., Foehr, U.G., and Rideout, V.J., 2005. *Generation M: media in the lives of 8–18 year-olds*. Menlo Park, USA: Kaiser Family Foundation.

Roelofs, A. and Straker, L., 2002. The experience of musculoskeletal discomfort amongst bank tellers who just sit, just stand or sit and stand at work. *Ergonomics Journal of South Africa*, 14, 11–29.

Saarni, L., *et al.*, 2007. Are the desks and chairs at school appropriate? *Ergonomics*, 50, 1561–1570.

Saito, S., *et al.*, 1997. Ergonomic evaluation of working posture of VDT operation using personal computer with flat panel display. *Industrial Health*, 35, 264–270.

Savanur, C.S., Altekar, C.R., and De, A., 2007. Lack of conformity between Indian classroom furniture and student dimensions: proposed future seat/table dimensions. *Ergonomics*, 50, 1612–1625.

Shieh, K.K. and Lee, D.S., 2007. Preferred viewing distance and screen angle of electronic paper displays. *Applied Ergonomics*, 38, 601–608.

Simoneau, G.G., Marklin, R.W., and Berman, J.E., 2003. Effects of computer keyboard slope on wrist posture and forearm electromyography of typists without musculoskeletal disorders. *Physical Therapy*, 83, 816–830.

Slijper, H.P., *et al.*, 2007. The effects of pause software on the temporal characteristics of computer use. *Ergonomics*, 50, 178–191.

Sommerich, C.M., Joines, S.M.B., and Psihogios, J.P., 2001. Effects of computer monitor viewing angle and related factors on strain, performance and preference outcomes. *Human Factors*, 43, 39–55.

Sommerich, C.M., *et al.*, 2002. Effects of notebook computer configuration and task on user biomechanics, productivity and comfort. *International Journal of Industrial Ergonomics*, 30, 7–31.

Sommerich, C.M., *et al.*, 2007. A survey of high school students with ubiquitous access to tablet PCs. *Ergonomics*, 50, 706–727.

Sotoyama, M., *et al.*, 2002. An ergonomic questionnaire survey on the use of computers in schools. *Industrial Health*, 40, 135–141.

Straker, L. and Abbott, R., 2007. Effect of screen based media on energy expenditure and heart rate in 9- to 12- year old children. *Pediatric Exercise Science*, 19, 459–471.

Straker, L., Briggs, A., and Greig, A., 2002. The effect of individually adjusted workstations on upper quadrant posture and muscle activity in school children. *Work*, 18, 239–248.

Straker, L., Jones, K.J., and Miller, J., 1997. A comparison of the postures assumed when using laptop computers and desktop computers. *Applied Ergonomics*, 28, 263–268.

Straker, L. and Mathiassen, S.E., 2009. Increased physical work loads in modern work – a necessity for better health and performance? *Ergonomics*, 52, 1215–1225.

Straker, L. and Mekhora, K., 2000. An evaluation of visual display unit placement by electromyography, posture, discomfort and preference. *International Journal of Industrial Ergonomics*, 26, 389–398.

Straker, L. and Pollock, C., 2005. Optimising the interaction of children with information and communication technologies. *Ergonomics*, 48, 506–521.

Straker, L., Pollock, C., and Burgess-Limerick, R., 2006a. Excerpts from CybErg 2005 discussion on preliminary guidelines for wise use of computers by children. *International Journal of Industrial Ergonomics*, 36, 1089–1095.

Straker, L., Pollock, C., and Burgess-Limerick, R., 2006b. Towards evidence based guidelines for healthy & wise use of computers by children. *International Journal of Industrial Ergonomics*, 36, 1045–1053.

Straker, L., Pollock, C., and Maslen, B., 2009a. Principles for wise use of computers by children. *Ergonomics*, 52, 1386–1401.

Straker, L., *et al.*, 2006c. *IT kids: exposure to computers and adolescents' neck posture and pain* [online]. Available from: www.iea.cc/ergonomics4children/pdfs/art0211.pdf [Accessed 20th February 2008].

Straker, L.M., *et al.*, 2006d. The association between information and communication technology exposure and physical activity, musculoskeletal problems and socio-economic status in 5-year-olds. *Child: Care, Health and Development*, 32, 343–351.

Straker, L., *et al.*, 2008a. Children's head, neck and upper limb posture and muscle activity at different computer display heights and during paper information technology use. *Human Factors*, 50, 49–61.

Straker, L., *et al.*, 2008b. The impact of computer display height and desk design on 3D posture during information technology work by young adults. *Journal of Electromyography and Kinesiology*, 18, 336–349.

Straker, L.M., *et al.*, 2008c. A comparison of posture and muscle activity during tablet computer, desktop computer and paper use by young children. *Ergonomics*, 51, 540–555.

Straker, L., *et al.*, 2008d. The impact of computer display height and desk design on muscle activity during information technology work by young adults. *Journal of Electromyography and Kinesiology*, 18, 336–349.

Straker, L., *et al.*, 2008e. Virtual electronic game playing by children can be active. *In*: *Proceedings of the Ergonomics Society annual conference*, Nottingham, UK: Ergonomics Society.

Straker, L., *et al.*, 2009b. The effect of forearm support on children's head, neck and upper limb posture and muscle activity during computer use. *Journal of Electromyography and Kinesiology*, 19, 965–974.

Straker, L., *et al.*, 2009c. The influence of desk and display design on posture and muscle activity variability whilst performing information technology tasks. *Applied Ergonomics*, 40, 852–859.

Straker, L., *et al.*, 2009d. Children have less variable postures and muscle activities when using new electronic information technology compared with old paper-based information technology. *Journal of Electromyography and Kinesiology*, 19, e132–e143.

Straker, L., *et al.*, 2009e. Effect of visual display height on modelled upper and lower cervical gravitational moments, muscle capacity and relative strain. *Ergonomics*, 52, 204–221.

Szeto, G.P.Y., 2003. *Potential health problems faced by an Asian youth population with increasing trends for computer use* [online]. Available from: www.iea.cc/ergonomics4children/sumtab.html [Accessed 2 April 2008].

Szeto, G.P. and Lee, R., 2002. An ergonomic evaluation comparing desktop, notebook and subnotebook computers. *Archives of Physical Medicine and Rehabilitation*, 83, 527–532.

Szeto, G.P.Y. and Sham, K.S.W., 2008. The effects of angled positions of computer display screen on muscle activities of the neck-shoulder stabilizers. *International Journal of Industrial Ergonomics*, 38, 9–17.

Szeto, G.P.Y., Straker, L.M., and O'Sullivan, P.B., 2005. The effects of speed and force of keyboard operation on neck-shoulder muscle activities in symptomatic and asymptomatic office workers. *International Journal of Industrial Ergonomics*, 35, 429–444.

Szeto, G.P.Y., Straker, L.M., and O'Sullivan, P.B., 2009. Neck-shoulder muscle activity in general and task-specific resting postures of symptomatic computer users with chronic neck pain. *Manual Therapy*, 14, 338–345.

Thompson, W.G., *et al.*, 2008. Feasibility of a walking workstation to increase daily walking. *British Journal of Sports Medicine*, 42, 225–228.

Trevelyan, F.C. and Legg, S.J., 2006. Back pain in school children – Where to from here? *Applied Ergonomics*, 37, 45–54.

Turville, K.L., *et al.*, 1998. The effects of video display terminal height on the operator: a comparison of the 15° and 40° recommendations. *Applied Ergonomics*, 29, 239–246.

Tuttle, N., Barrett, R., and Gass, E., 2007. Seated buttock contours: a pilot study of Australian senior high-school students. *Ergonomics*, 50, 1593–1602.

van den Heuvel, S.G., *et al.*, 2006. Do work-related physical factors predict neck and upper limb symptoms in office workers? *International Archives of Occupational and Environmental Health*, 79, 585–592.

Veiersted, K.B., Westgaard, R.H., and Andersen, P., 1993. Electromyographic evaluation of muscular work pattern as a predictor of trapezius myalgia. *Scandinavian Journal of Work, Environment and Health*, 19, 284–290.

Villanueva, M.B., *et al.*, 1997. Sitting posture and neck and shoulder muscle activities at different screen height settings of the visual display terminal. *Industrial Health*, 35, 330–336.

Wærsted, M. and Westgaard, R.H., 1997. An experimental study of shoulder muscle activity and posture in a paper version versus a VDU version of a monotonous work task. *International Journal of Industrial Ergonomics*, 19, 175–185.

Wahlström, J., *et al.*, 2000. Working with the computer mouse – differences between work techniques and gender. *Scandinavian Journal of Work, Environment and Health*, 26, 390–397.

Wake, M., Hesketh, K., and Waters, E., 2003. Television, computer use and body mass index in Australian primary school children. *Journal of Paediatric Child Health*, 39, 130–134.

Westgaard, R.H., 2000. Work-related musculoskeletal complaints: some ergonomics challenges upon the start of a new century. *Applied Ergonomics*, 31, 569–580.

Williams, I.M., 2002. Students' musculoskeletal and visual concerns. *In*: *The Proceedings of the XVI annual international occupational ergonomics and safety conference* [online]. Available from: http://cehd.umn.edu/kls/ecee/pdfs/StudentsMuscAndVisualConcerns_Williams.pdf [Accessed 11 May 2008].

Woods, V., *et al.*, 2002. *Ergonomics of using a mouse or other non-keyboard input device*. HSE research report 045. London: Health and Safety Executive.

Zandvliet, D. and Straker, L., 2001. Physical and psychosocial aspects of the learning environment in information technology rich classrooms. *Ergonomics*, 44, 838–857.