Can ‘eye’ tell if you are paying attention? The use of mobile eye-trackers to measure academic engagement in the primary-school classroom.

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Abstract

Although much research has examined the construct of academic engagement using behavioural measures such as observations and recording video footage of classrooms, there is little taking advantage of the development of technology enabling researchers to measure possible behavioural indicators of visual attention. The technology in question is a device with the capability to track the eye movements of the wearer whilst in their naturalistic environment. With this in mind, a novel idea was proposed, aiming to establish a link between academic engagement, selective attention and eye-tracking. Therefore, the goal of the present study was to test the feasibility of implementing a mobile eye-tracking device in a primary school classroom as a measure of visual attention, and consequently of academic engagement. One classroom at a local school was used for the study, where the gaze patterns of primary-school aged children were collected during sessions of either literacy or numeracy teaching, with the prediction that the naturally-occurring differences between classroom activities ('teacher instruction' and 'classroom discussion') would affect where children directed their gaze within their classroom. The main difference found was that children were more likely to fixate onto their close peers or their own work during 'classroom discussion', compared to aspects of the environment relating to the teaching of instruction, such as a whiteboard display during 'teacher instruction'. Additionally, findings suggest that school-children generally remain 'on-task' during periods of 'teacher instruction' and 'classroom discussion', however, they still express some level of distractibility during periods of observation. Understanding how children deploy their attention in an academic context has wide implications, from both a developmental and educational perspective. The feasibility of applying alternative methods such as this research paradigm will be addressed, with suggestions for future adaptations.

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Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References.

Introduction

This research aims to relate themes within education and psychology to further investigate the processes involved in learning. Only recently have well-established theories of learning within the field of developmental and cognitive psychology been linked with educational research. Current research has established that the ability to pay attention, or stay ‘on-task’ is a prerequisite of learning (Schunk, 2008). Similarly, Posner and Rothbart (2014) expressed the importance of successful development of the attentional network throughout childhood for later academic achievement. Selective attention is often defined as “the ability to focus our cognitive resources on information relevant to our goals” (Gazzaley & Nobre, 2012). Selective attention is a particularly important skill to possess in the classroom, as it allows a child to willingly concentrate on what is important whilst being able to ignore irrelevant distractions (Stevens & Bavalier, 2012). For this reason, it has been suggested that selective attention has a positive effect on several academic domains such as language, literacy, and mathematics, and therefore later academic achievement (Capie & Tobin, 1981; Martin, Olejnik, & Gaddis, 1994; Duncan et al, 2007). Selective attention is usually measured using a number of well-established paradigms such as visual search tasks (Wolfe, 1994), but for the sake of increasing ecological validity, it is proposed here that mobile eye-trackers could be used to measure visual selective attention processes in the classroom.

In an educational context, eye-tracking methodology aims to measure the interaction between learner and stimulus or environment (Knight, Horsley & Elliot, 2014). This concept is based on the eye-mind assumption proposed by Just and Carpenter (1980), who suggested that eye movements can provide a dynamic trace of where attention is being deployed (Rayner, 1998). Therefore, in an educational setting the recent application of eye-tracking methodology has been paramount to providing a valuable insight into the cognitive and visual processes involved in scholastic learning, by measuring what learners in multiple educational settings are visually attending to.

It is important to recognise that many factors influence scholastic learning and eventual academic achievement, but the focus of this research will be relating visual attention to the learning process. By measuring eye gaze in a classroom environment that warrants optimum levels of attention, the research will serve as a direct observation of how learning might occur by linking eye-tracking data to theorised cognitive processes. Children who are in the stages of primary education will be experiencing developmental changes relating to their attentional network, at differing rates that can only be explained by individual differences. Therefore, this research aims to further develop the application of eye-tracking methodology in educational studies, by observing the complex environment of the classroom and how individual children attend to the multisensory environment they are presented with.

The research question developed as means to take the well-established research methods involved in tracking eye gaze in laboratory settings into more naturalistic environments. Previous research in education and psychology has focussed on capturing visual attention by measuring eye gaze in laboratory settings using static eye-trackers, and despite the positive implications of such research being conducted, issues with validity often arise. The lack of generalizability is further supported by research suggesting that deployment of attention differs considerably between laboratory settings and naturalistic settings (Gidlof, Wallin, Dewhirst and Holmqvist, 2012). Therefore, the implications for both psychological and educational research from the development of mobile eye-trackers have been positive, in that they can be used across a range of environments to link eye movements to cognitive processes such as learning, reading and decision-making behaviour (Blignaut, Holmqvist, Nystrom & Dewhurst, 2014).

Based on previous research, it could be suggested that measuring visual attention and using it as a proxy of academic engagement, has not been done before. Due to the relatively recent development of mobile-eye-tracking equipment, their suitability for use with young children is questionable as most have been designed for use with adult subjects. Therefore, this research breaks new ground by dynamically tracking eye movements of primary school-aged children in an environment they spend a considerable amount of time in: their classroom.

Thesis Outline

Literature Review

This section will be devoted to a review of past and present relevant literature, by outlining findings and issues that assert the context of this research project. By doing so, this section will highlight what has been addressed and still needs addressing in research relating to the link between attention and engagement, eye gaze, and learning and development.

Method

This section of the thesis will clearly define the methodology adopted when conducting this research, such that each step could be replicated by someone who is blind to the research. The research method and procedure, such as recruitment of participants and ethical issues are clearly described, providing justification for the selection of such methods and procedures. Finally, the write-up will address the collection of data, also with some discussion of the processes implemented for readying the gaze data for analysis, and a description of each stage of analysis that led to the final presentation of the data.

Results

The results section is designated to discuss how the data has been made fit for analysis and what statistical analysis techniques have been used to extrapolate informative findings from the data.

Discussion

The discussion section will conclude the write-up, by summarising the main findings of the study and providing possible explanations for the findings. The research methods and procedure will be closely critiqued. Since the use of mobile eye-trackers in naturalistic settings is a relatively underdeveloped research technique, it is important to assess the validity of applying such methods. The implications of the study will also be discussed.

Literature Review

Attention and Learning

There are many benefits to achieving academically, from financial to social and health (Valiente, Eisenberg, Spinrad, Haugen, Thompson & Kupfer, 2013), and studies have consistently shown that educational achievement at the age of sixteen is the most important predictor of future participation in learning and of labour market prospects (Pearce & Hillman, 1998) in the United Kingdom (UK) and United States (US) alike. Following on from this point, there are many factors influencing whether a child is more or less likely to achieve along their academic trajectory. Early research identified the importance of an individual's mental ability in relation to educational attainment (Sewell, Haller & Portes, 1969).

First and foremost, it is logical to suggest that learning has a central role in education, and the term 'learning' covers all manner of different skills being addressed in scholastic environments. Hilgard and Marquis (1961) defined learning, free from the educational context as "experience which produces a relatively permanent change in behaviour or potential behaviour.", thus inferring that humans possess the ability to learn how to benefit from their experiences, by building up progressively more sophisticated internal models or representations of their environment (Howe, 1980). Learning can occur across many different domains, with early research tending to focus on cognitive, affective and psychomotor skills. As a result of cognitive models of learning being the dominant paradigm over the past three decades in both academic psychology and education (Jarvis, 2005), the formal curriculum in the United Kingdom aims to enhance cognitive abilities in pupils, by promoting the pursuit of knowledge, comprehension and application of these skills. From the perspectives of cognitive research, a prerequisite to the application of these skills is that children develop higher levels of thought based on symbolic representations. This allows children to form mental representations of events, things or ideas and provides the foundations for acquiring knowledge about the world around them. However, the effectiveness of the national curriculum for encouraging these skills has been questioned, where research states that there is less emphasis on these abilities, especially those relating to language and as a result, children are not developing the necessary skills to thrive in later life.

Arguably, the benefits of developing knowledge would be futile but for the reported interchange between short-term and long-term memory stores (Baddeley, 2000). The memory serves as a storage component of abilities that have been learnt over time, and education should be directly concerned with methods of ensuring that information is successfully inputted to long-term memory, for it to be subsequently reproduced and used where necessary. Short-term memory, or what is sometimes referred to as working memory, is said to act as a kind of mental jotting pad that stores information necessary for everyday activities such as remembering telephone numbers and following directions and instructions (Gathercole, Pickering, Ambridge, Ambridge & Wearing, 2004). Research suggests that working memory consists of several interacting subsystems that serve specific modalities, such as the processing of visuo-spatial and verbal information, and additionally, an attentional component (Baddeley, 2000). The classroom environment is known to impose heavy demands on working memory, due to the diverse teaching techniques adopted by educators at all levels (Gathercole et al, 2004).

Furthermore, an important pre-cursor to the consolidation of content and development of knowledge is the ability to distinguish between relevant and irrelevant stimuli in the environment, and therefore to be able to glean the most information from the salient stimuli whilst disregarding the irrelevant parts. This well-researched, specific ability to be able to pay attention, or stay ‘on-task’ is reportedly a necessary prerequisite of learning (Schunk, 2008). Posner and Rothbart (2014) discussed the recent interest in the relationship between human attention systems and learning, and stated that explicit learning of concepts, memory, and attention are central to success in school. Paying attention to selected stimuli and ignoring others (selective attention) limits the possibilities of what we can perceive and process. This claim can be substantiated by research stating that we can only fully pay attention to one cognitively demanding task at a time (Anderson, 2005). This is of great benefit to humans, where the visual system has adapted to reduce the amount of incoming visual data to a small but relevant amount of information for higher-level cognitive processing (Walter, Rutishauser, Koch & Perona, 2004). Specifically what humans pay attention to is guided by prior knowledge about scenes, objects and their inter-relations. Attention is also affected by what else is happening at the time, complexity of the task presented to them and the individual ability to control or focus attention (O'Driscoll et al, 2005). Unfortunately, there are restrictions due to the limited capacity of the human attention system, and where attention is divided and attentional demands exceed capacity, task performance suffers. Attentional shifts and cognitive overload can prevent information being adequately processed and can interfere with learning (Chun & Wolfe, 2001).

Development of Attention Processes

As with many skills, the foundations for attentional skills are laid down from the very earliest stages of life (McNeil, 2009). Before children reach five years of age, they exhibit spontaneous deployment of attention, which changes rapidly from one object to another. However, once children are near to school-age they are better able to concentrate for longer periods and they develop what is known as the orienting network, and this allows them to attend to external signals regardless of sensory modality, therefore in an educational context this is important for reducing distraction and amplifying input relevant to the subject being studied (Posner, Rothbart & Tang, 2013). This ability to deploy attention develops throughout childhood, as a result of brain maturation initially and then interaction with the environment as the child progresses towards adolescence (Vuontela et al, 2013). However, the concept is not so simple, as there are many different factors influencing the ability to control attention, such as hyperactivity, intelligence and learning disabilities (Grabe, 1986). Therefore, the discussion of these points highlights the importance of paying attention in the process of learning and how this ability develops, as Lachter, Forster and Ruthruff (2004) also stated that learners cannot process information if they do not acknowledge, recognise or perceive things within their environment. Additionally, from a social-developmental perspective, Bronfenbrenner (1979) stated that children learn by paying attention to other people, events and aspects of their environment that they find meaningful and enjoyable. Therefore, through the process of socialisation, children begin to develop the ability to concentrate on tasks, and as they grow they are presented with cognitively challenging tasks and verbal interactions around such activities further encourage cognitive development.

Attention, the Developmental Trajectory and Academic Success

There are many factors that are said to influence a child's potential to develop and thrive in the school environment. For this reason, the magnitude of the problems with potential underachievement are huge. Underachievement is defined by Thorndike (1963), as "…achievement falling below what would be forecast from our most informed and accurate prediction, based on a team of predictor variable", which basically implies relatively poor academic performance. The current education system in the UK measures academic performance using standardised tests, to determine whether students' performance aligns with nationalised levels and this level of achievement fundamentally determines the course of an individual's life. Pearce and Hillman report that the prospects for those who leave the education system with little or nothing to show for it are poor.

Consequently, a positive relationship between successfully being able to pay attention and academic attainment, was highlighted in a piece of longitudinal research conducted by McClleland, Acock, Piccinin, Rhea and Stallings (2013), investigating the relationship between children's attention span and educational outcomes between pre-school age through to adulthood, and found that if children were better able to pay attention at age four it was a significant predictor of later mathematics and reading achievement when aged twenty one. So, based on these presented findings, it is inevitable that a negative relationship exists between attentional difficulties and academic attainment. For those who do not reach the attention levels of their peers developmentally, the effects of poor academic attainment are very well-documented. The skills that are obtained from consistently being attentive in schools contribute to students' long-term cognitive development. The development of cognitive abilities such as selective attention, are the best and broadest predictors of adult adjustment from childhood, whereas consistent inattentive behaviour appears to undermine academic achievement throughout the school years and this academic failure in turn appears to contribute to worsening inattentive behaviour (Masten et al,2005). Hinshaw (1992) found that childhood inattention is a stronger predictor of academic problems, compared with aggression. Later research replicated these results, where teacher-rated inattentiveness was linked with lower attainment levels in a study by Merell and Tymms, 2010).

Attention and Academic Engagement

The notion of paying attention in academic contexts is often overlapped in research literature with the concept of engagement, which is broadly described by Marks (2000) as a growth-producing activity through which individuals allocate attention in active response to their environment. An extension of this is academic, or school engagement, which can be defined as a "psychological investment in and effort directed toward learning, understanding, or mastering the knowledge, skills, or crafts that academic work is intended to promote" (Marks, 2000). Academic engagement is often explained using a multidimensional approach, based on the findings from research on school engagement spanning the past three decades (Maynard, Beaver, Vaughn, DeLisi, and Roberts, 2014). Therefore, school engagement is often theorised to consist of three components, these being affective, cognitive and behavioural subtypes. The affective aspect hones in on students' feelings about school, encompassing issues involving peers and teachers also (Fredricks et al, 2004), and these feelings are often measured using self-report methods. The cognitive aspect addresses pupils' perceptions and beliefs about school, such as their psychological investment in learning. This research is primarily interested in identifying levels of academic engagement from the behavioural perspective, which encompasses the occurrence of behaviour directly related to the learning process, such as attentiveness, participation, and effort and initiative taking in the classroom. A further indication of academic engagement often adopted in this research area involves observing pupils' time 'on-task' in the classroom (Rimm-Kaufman, La Paro, Downer & Pianta, 2005), or on a longitudinal basis, observing changes in academic performance over time.

Moreover, researchers have highlighted school engagement as a factor of paramount importance to the developmental trajectory and academic achievement of students through all grade levels (Maynard et al, 2014), whereby the school-engagement hypothesis (Marks, 2000) suggested that the more proficient pupils are at utilising engagement throughout the educational process the more their engagement will continuously contribute to students' social and cognitive development. As a result of the positive relationship between engagement and development, students who are engaged in school are more likely to learn, to find the experience rewarding, to graduate and pursue higher education.

Therefore, one suggestion would be that those who are less proficient at engaging with school and classroom activities would suffer both developmentally and academically. This was found to be the case in a study examining the academic attainment of over 1000 primary school students, where they were also rated for their attentiveness and disruption in the classroom (Finn & Pannozzo, 1993). The research found that the children who were classified as 'disengaged' were significantly impaired academically, compared with both the 'compliant' and 'disruptive' groups of children's scores on standardised tests. Interestingly, children rated as both 'disruptive and disengaged' expressed achievement levels very similar those rated as 'disengaged', which highlights the point that the more children withdraw from participation in the classroom, the more likely they are to fall behind with the curriculum and it becomes very difficult for them to learn compared to their 'attentive' peers. Ladd and Dinella, (2009) found that those children who exhibit decreased levels of academic engagement across the primary grades display lesser scholastic growth compared to children who participated cooperatively in classrooms. This implies that the process of academic disengagement can begin early in the educational journey, so if the child does not fit in and participate from a young age; it makes it more difficult as they move through the grade levels to develop the necessary skills to enhance academic engagement, thus reducing the likelihood of academic achievement. The consequences of early academic disengagement accumulate as students attend secondary school, where they continue to be disengaged with their education and therefore will have poor relationships with peers and teachers. As a result of this, they are more likely to use drugs; engage in socially disruptive behaviour and fail to complete secondary school (Bond et al, 2007). The reasons contributing to why young people might become disengaged with learning have been well-studied, as researchers are increasingly interested in why most students begin school enthusiastic, optimistic and eager to learn, but this is often short-lived and the positivity slips away the longer the children are in school (Alexander, Enwisle & Horsey, 1997).

It is apparent that no common trajectory of school engagement exists, as individual differences amongst pupils either positively or negatively impact their development and later academic attainment. Thus a large body of research has sprung from this notion, aiming to identify factors that might directly or indirectly affect school engagement, Maynard et al, (2014) summarised that a number of factors across a number of domains are in some way linked to school engagement, and that these factors can be broken down into individual factors such as autonomy, intrinsic motivation, self-efficacy and positive affect amongst others, as well as peer factors such as the level of peer support that a pupil is receiving, the perceptions of peer group academic values and the importance of peer group membership. Thirdly, family-related factors such as socioeconomic status, parental support and parents' level of academic attainment are said to have some effect on pupil's school engagement. Finally, school engagement is also influenced by factors relating to pupils' schools and their classroom environment, with research findings highlighting the importance of positive learning environments, positive pupil-teacher interactions, cooperative learning, school size and overall positive school climate. Therefore, it is clear that a multitude of individual and contextual factors are influencing school engagement

Measuring Academic Engagement

Academic or school engagement is often measured through a variety of constructs, with a prominent element being the aforementioned observation of behavioural engagement within classroom settings. In earlier research conducted into student engagement, Finn and Voelkl (1993) divided the concept of engagement into two different, but wholly related concepts. The first of these was termed as participation, which basically referred to the extent to which a student regularly participated in classroom activities, and the level and type of participation developed as the student progressed through their respective education system. Finn and Voelkl (2003) stated that at the most basic level, participation involved children attending school, paying attention to the teacher and taking part in classroom activities by responding to instruction. Fredricks et al, (2004) extended the classification of behavioural engagement, or participation, in a number of ways. The first definition relates to positive conduct, such as following rules and adhering to classroom norms. The second definition relates to involvement in learning and academic tasks and includes behaviours such as effort, persistence, and concentration, attention, asking questions and contributing to classroom discussions. Therefore, extending this idea, research has frequently referred to direct participation in classroom activities and therefore learning as “on-task” behaviour, and this is often used as a proxy of behavioural academic engagement. Fisher, Godwin and Seltman (2014) state that with respect to pupil’s academic achievement, the more opportunities one has to learn, the better the learning outcomes, and this is known as a the ‘time-on-task hypothesis’. Gill and Remedios (2012) highlight the difficulty of operationalising this form of engagement because of the idiosyncratic nature of what might be deemed as ‘on-task’ in the classroom; it is all dependent on the activity. For example, in collaborative learning environments, social interaction with peers to relay ideas and distribute knowledge between the groups could be categorised as being ‘on-task’. However, this sort of behaviour during ‘teacher instruction’ would be deemed as actively disruptive to the situation and therefore ‘off-task’.

Studies such as that by Godwin, Almeda, Petroccia, Baker and Fisher (2011), apply this idea and investigate ‘off-task’ behaviour in the classroom as an attention measure by using observational methods. They coded the frequency of ‘on-task’ and ‘off-task’ behaviour, and what this ‘off-task’ behaviour entailed. For example, whether pupils distracted themselves, their peers did or whether something in their classroom environment was a form of distraction. From a learning perspective, all activities not directed towards learning can be viewed as ‘off-task’ behaviour. Hofer (2007) states that ‘off-task’ behaviour can be active, where pupils are actively engaging in behaviour that is disruptive to the classroom or it can be passive, where pupils become cognitively disengaged without disrupting others. The phenomenon of ‘off-task’ behaviour remains a current issue in daily teaching, and regardless of whether or not this type of behaviour is detected by teachers, it will not amount to learning because academic achievement is positively linked to the amount of attention pupils pay during teaching instruction, and therefore negatively correlated to the frequency of task-irrelevant cognition. Furthermore, cognitive theory suggests that at any moment in time, attention is determined by two factors: sensory activation or relevance. Therefore, Norman’s pertinence model (1968) suggests that an attentional shift can occur if a stimulus is strong enough to capture a pupil’s attention. This can also be described as distractibility, and much significant impairment found in children’s academic performances is attributable to distractions (Higgins and Turnure (1984). But it is well documented that distractibility does decrease markedly with age (Higgins & Turnure, 1984), and this is attributed to developmental improvements in area of executive function, such as the process of selective attention.

The observation of ‘off-task’ behaviour is a method often adopted by research in a clinical context (Gill & Remedios, 2012). A prime example of this is seen with pupils in the classroom who exhibit traits associated with ADHD. The attentional difficulties, such as heightened distractibility (Gumenyuk et al, 2005) make concentrating on school work and instruction very difficult. Therefore, Reiber and McLaughlin (2004) assert that those with attentional difficulties would benefit from an orderly environment, and this makes the classroom structure one of the most salient areas of instructor influence in the classroom. Heightened sensory activation is likely to occur when there are multiple uses of displays with bright colours in a classroom, and this creates unnecessary distractions for those who already struggle to remain ‘on-task’ in the classroom.

Classroom Environment and Academic Engagement

Furthermore, classroom environments are said to influence the way students behave (Guardino & Antia, 2012). Limited recent research into the effects of classroom environmental factors on academic engagement suggests that children are most likely to be negatively affected by distractions in the form of displays, and this phenomenon was investigated in a snapshot study where Godwin et al (2011) manipulated classroom environments to test the effect of “low visual distraction” versus “high visual distraction” on pupils’ ability to maintain attention on the content of the instruction being delivered. The researchers found where there was little distraction children were more engaged and obtained higher learning scores, compared to the environment where the level of visual distraction was deemed to be high. This is a prime example of when the capacity of human attention and processing of information is selective and limited (Posner, 1982; Walther et al, 2004). Too many sources of information could create cognitive overload, where new information coming in can cause attentional shifts and distraction. According to Fried (2006), anything visually salient or prominent would be inherently distracting within the classroom. This presents issues for educators who wish to both educate their young students and also keep them engaged in the process of learning (Kaminsky & Sloutsky, 2013). It is thought that once they reach middle childhood, children are able to effectively sustain attention whilst in the presence of a distraction (Halperin, 1996), and this ability is said to facilitate goal directed behaviour. In order to do this, educators may prepare attractive visual displays of information to assist in explaining the concept they are teaching, as reported by Kaminsky and Sloutsky (2013), who implied that extra pictorial input may be visually appealing, but such information may hinder, rather than facilitate learning. Therefore, the existence of extraneous information in a learning environment may capture their already quite limited attention, and discourage them from focussing on the concept to be taught by the educator (Guardino & Antia, 2012). It is expected that one will become distracted by extraneous, important environmental stimulation but for this ability to be deemed adaptive, children of middle childhood should be able to reorient attention to the original task (Kercood & Grskovic, 2010). However, the ability to effectively sustain attention develops at different stages of children's development. Therefore within a classroom, the influence of individual differences between cognitive abilities should always be considered.

There are some additional factors that are important when considering influences on children's ability to remain engaged in academic settings, such as the type and content of instruction that is delivered by the teacher, how it is received by the children, and the layout of the classroom. Guardino and Antia (2012) suggest that the physical layout of the classroom can affect learning, where certain kinds of seating arrangements can facilitate student discussion but can also give rise to distractions during individual work (Zifferblatt, 1972). Zifferblatt stated that seating needs to be arranged so that students can engage in individual and participate in group work sufficiently. Guardino and Fullerton, (2010) conducted a study that attempted to carry out this theory, by working with a classroom teacher to create distinct individual and group work spaces, whilst also rearranging the furniture to reduce the risk of distractions. They found that after the modifications were made, academic engagement increased by approximately 42%, but the originally perceived reduction in disruptive behaviour was not stable over time. This research is one of the most recent, and only studies investigating how the classroom environment affects student engagement. Furthermore, often classrooms are cluttered with furniture which can result in students constantly bumping into one another and elevating the risk of disruptive behaviour occurring. Also, a disorganised classroom where materials are in unfamiliar locations can reduce instructional time and increase the opportunities for students to engage in disruptive behaviour (Guardino & Fullerton, 2010).

Therefore, it is apparent that numerous aspects of the classroom environment have considerable effects on pupils' ability to maintain focussed attention during instruction, based on research conducted using observational measures in the classroom, some in naturalistic environments and some in manipulated laboratory settings (Fisher et al, 2014). However, observational methodology is often criticised as being unreliable, due to the fact it is based on researchers' interpretation of the behaviour presented to them visually (Rosenbaum, 2002), and the claims made are often ambiguous and lacking in evidence. Therefore, in order to further investigate the previously established relationship between classroom environment and focussed attention, an alternative measure for determining engagement in the classroom could be the direction of gaze; as eye gaze is considered a common measure of visual attention (Just & Carpenter, 1984). It can be argued that engagement can be determined by the direction of gaze, and although it is possible in an educational context that pupils can be listening to the teacher whilst looking elsewhere, doing so by definition constitutes divided attention rather than focused attention (Fisher et al, 2014). Therefore, in instructional contexts that involve visual content, direction of eye gaze is a reasonable but imperfect measure of focused attention and 'on-task' behaviour.

Thus, the relationship between the two constructs based on past and current research will be discussed, as well as an evaluation of the development of the technology used to measure eye gaze and how this will be applied to the present research study.

Eye Gaze and Tracking

Out of the five major senses, sight is probably the most highly developed in humans and arguably the most important (Driver, Davis, Ricciardelli, Kidd, Maxwell & Baron-Cohen, 1999), so much so that more than 50% of the cerebral cortex of the brain is involved with the processing of visual information (Driver et al, 1999). Therefore, vision supports many critical functions, such as navigational processes and integration with the motor systems by guiding humans’ reading, grasping or pushing in physical interaction with the world. Conversely, vision also supports many higher level mental processes. Often visual details help to form our memories of places and people and may also be used to help manipulate abstract relations and concepts. The gathering of knowledge about vision derives from the study of visual psychophysics, which looks at the relationship between the physical stimulus in the outside world and the how that is connected to human performance. It has played a central role in the understanding of human visual capabilities and the brain.

Of particular interest within the visual system are human eye movements. These movements are controlled by three pairs of muscles, and are responsible for the horizontal, vertical and torsional eye movements, hence controlling the three-dimensional orientation of the eye inside the head. Moreover, based on previous research it is understood that large parts of the brain are engaged in controlling these muscles so they direct the gaze to relevant locations in space (Corbetta, 1998). Therefore, the movement of eyes and where they are looking, whether it is at another human or the environment, provides information about many aspects of human behaviour. Not least how we interact with visual stimuli but also as an expression of intimacy, regulation of interactions with others, exercising of social control and the ability to facilitate service and task goals (Kleinke, 1986).

Cognitive Processing and Eye Gaze

Many species have been reported to gaze towards regions of the environment that are currently of interest to them, and can portray considerable information to an observer as a means to signal the party’s current interests (Driver et al, 1999). In this way, the observer is placing all their conscious emphasis on a particular position, allowing the most sensitive visual receptors to analyse and interpret it. However, Driver et al (1999)’s research suggests that orienting attention is not always a covert, conscious process, and often even without intention the eyes orient towards and fixate on presented stimuli. Research by Henderson, (2003) supports this idea, were findings suggest that the visual cognitive system controls gaze to fixate towards important and informative real scenes and that the human visual acuity and colour sensitivity are best at the point of fixation. For this reason, Henderson (2003) states that “eye movements serve as a window into the operation of the attentional system”.

Eye movements with the purpose of repositioning gaze are known as saccades (Ross, Morrone, Goldberg & Burr, 2001), and are reported to occur several times per second as we scan the world (Snowden, Thompson & Troscianko, 2012). In most natural situations, we explore a visual scene by the means of saccadic eye movements that rapidly bring the fovea, the retinal region of highest acuity, and the neural machinery associated with it onto stimuli of interest (Corbetta, 1998). The experiments of Yarbus (1956) established a link between saccadic eye movements with cognitive processes. In support of this, a number of psychophysical and imaging studies support the idea that focusing of attention by the observer is usually reflected in fixations (Findlay & Gilchrist, 2003), that usually last for around 200-300ms whilst saccades take around 30ms and infer a shift in attention. These types of saccades are said to be under endogenous control, as they often intentional or voluntary and have longer latencies than reflexive saccades under exogenous control do. A complex network of subcortical functions is said to influence the generation of saccadic movements, where there is an apparent trade-off between “bottom up” signals concerning basic stimulus properties such as position, size and luminance, and “top down” signals that reflect the current goals and intentions of the observer (Hutton, 2008). Therefore, this process allows adults to switch endogenous and exogenous modes depending on the particular stimulus conditions (Theeuwes & Godijn, 2001). Whether the networks linked to saccadic movements can be explicitly associated with attentional networks remains a contentious debate, but it seems feasible to suggest, based on research by Johnston and Everling (2008), that the systems do overlap considerably. Research has linked oculomotor movements with selective attention (Rizzolatti et al, 1987). Selective attention is a process that occurs both covertly and overtly, where attention can be directed to a location in space without movement of the eyes (covertly). Also, the fact that attention appears to precede overt movement of the eyes contests the idea that eye movements and cognitive processing are closely associated. However, it is generally agreed upon that there is an obligatory and selective coupling between saccade execution and visual attention to common targets (Theeuwes & Godijn, 2001).

Eye-Tracking Technology

A lot of laboratory-based research has been conducted assuming a link between attention and eye movements, for example the use of eye movements as an index of which aspects of a scene or stimulus such as a face received most attention (Hutton, 2008), therefore serving as an implicit measure of what an observed is thinking about or where the observer is getting information from. This research methodology has been driven by the development of portable eye-trackers that are worn by participants, which make it possible to track gaze duration and fixations using computerised software

Interest in eye gaze research increased with the rise in popularity of the cognitive psychology movement, where most research adopted behavioural methodology (Kleinke, Desautels & Knappe, 1977; Kleinke, 1986). For example, research in laboratory settings where researchers recorded when gaze behaviour occurred between two people, and where video cameras were used to measure gaze as the research area grew in popularity. From the mid-1970s the technology really began to thrive and researchers were able to buy readily-made eye-trackers instead of having to build them themselves, and as a result of this the availability has increased enormously.

Video-Based Eye-tracking

The most popular eye gaze research techniques use video-based methods for measuring eye movements, due to the fact that they provide a relatively simple and cost-effective way of gathering two-dimensional records for analysis (Wyatt, 2010). Video-based eye-trackers use a video camera that focuses on one or both eyes to record eye movements, and typically an infrared light generated by the device is reflected from the eye, usually the front surface of the cornea which acts as a convex mirror (Guestrin & Eizenmann, 2006), which is then sensed by a video camera. The information is then analysed in order to extract eye rotations and points of gaze from changes in reflections from the eye. Inferring orientation of the eyes in this way is known as pupil-centred corneal reflection. For video-based measurement of eye movements, the pupil is very important. Also, the other important but less familiar element on the eye ball is the cornea. The cornea covers the outside of the eye and reflects light. When tracking the eyes of participants, we generally only want one reflection so we record infrared, to avoid all natural light reflections, and typically illuminate the eye with an infrared source. Therefore, the resulting corneal reflection is known as a 'glint' or the '1st Purkinje reflection'.

This methodology has been practised for over 40 years, but there is no unifying theory that explains the performance, limitations and potential of the technique available. The evaluation of eye-tracker methodology is on-going, due to eye movement research increasingly becoming a major topic of interest across a number of fields (Thompson et al, 2012).

Eye-Tracking Research

Much research using eye-trackers has been conducted, but a large proportion of this research predominantly focussed on capturing visual attention by measuring eye gaze in laboratory settings using eye-trackers, for example Mason, Tatkav and Macrae (2005); Rothkopff, Ballard and Hayhoe (2007); Castellhano, Mack and Henderson (2009). At the current time, there appears to be a shift towards adopting research methods at the level of phenomenon of interest, so if the research aims to address gaze patterns in real-world settings, then it should be conducted in real-world settings (Ristio, Laidlaw, Freeth, Foulsham & Kingstone, 2012). Foulsham et al, (2011) stated that eye-tracking research in laboratory settings often involves participants being placed in a stationary set up where their heads and bodies might be restrained, which does not seem a natural position in which to be observing stimuli, and the stimuli itself is often a representation of real-life in the form of photographs or video footage. Therefore, most research on visual attention has been conducted using static stimuli (Gidlof et al, 2012), but due to advances in technology, such as the availability of mobile eye-trackers, there has been a movement towards using naturalistic environments for this type of research (Gidlof et al, 2012).

Eye-trackers in Educational Settings

One of the earliest publications of eye gaze research done in a naturalistic environment was that by Tai, Loehr and Brigham (2006). They aimed to explore the use mobile eye-trackers to study student problem solving strategies for science assessment, and though the findings are not of great importance, the interest lies within the research methodology. Eye gaze tracking was deemed by the authors as a successful technique for identifying individual's more or less efficient attentional allocation routines in problem-solving. The idea of measuring visual attention in educational settings was also investigated by Rosengrant, Hearrington, Alvarado and Keeble (2012), who interpreted gaze patterns as measure of whether undergraduate students were paying attention in lectures or not. Rosengrant et al, (2012) stated that although the use of eye-trackers was generally successful in inferring allocation of attention, the method should not be used independently, as it only shows where someone is looking, and not what they are thinking. So, it was recommended that some other quantitative measure or qualitative measure such as self-reports or interviews are conducted alongside collection of eye-tracking data.

Moreover, the application of eye gaze tracking in naturalistic settings appears to have implications in a number of research areas. For instance, Noris, Nadel, Barker, Hadjikhani and Billard (2012) applied the use of mobile eye-trackers to research investigating the gaze of autistic children in a naturalistic setting, as a result of this type of research being scarcely found. The researchers stated that previously, they had been unable to conduct research from the eyes of the participant due to technological difficulties, but now with the availability of the mobile eye-trackers, they were able to use a reliable measure of where and what the participant is looking at. The implications of such research are many, which is why the method is becoming increasingly popular in many fields of research, such as neuroscience, psychology and even consumer businesses (Gidlof et al, 2013, Magrelli et al, 2013).

Research Statement

Therefore, the aim of this research is to use eye-tracking as a measure of visual attention. Also of interest is the link between visual attention and academic engagement, where eye-trackers will be used to track the gaze patterns of the young pupils during their involvement in classroom activities to determine whether they are engaged ('on-task') or disengaged ('off-task') with their tasks. Furthermore, the research will aim to validate the use of such methodology as a measure of academic engagement in the naturalistic setting of the classroom.

There is little in the way of previous research to predict how the primary school aged children will respond to having their gaze patterns recorded with a head mounted device whilst being in their respective classrooms, but it would be reasonable to consider the 'Hawthorne effect'. This phenomenon is generally defined as the problem in research that participants' knowledge that they are in an experiment modifies their behaviour (Adair, 1984), and it is often difficult to monitor in experiments conducted in naturalistic settings (Rosengrant et al, 2012). However, it is reasonable to suggest that this effect will only last for a brief period of time during the eye gaze pattern recordings, as the children wearing the glasses will become acclimatised to them and will hopefully exhibit 'normal' classroom behaviour. Therefore, the aim of this research project is to assess the success of implementing innovative measures of eye movement in a classroom setting as a measure of attention/engagement, with the device providing a measure of eye gaze that can be analysed temporally and spatially. In addition, the research explores how the gaze patterns of the wearer change over a period of time and how they focus on their environment, specifically in their classroom at any one time. Furthermore, based on previous research (Higgins & Turnure, 1984), it is expected that the children's attention to gaze targets will be affected by aspects of their environment, such as the appearance of the classroom, naturally occurring distractions and the instruction received from the class teacher. The children's demographic information will be considered as a potential factor that could influence results. For example, is disengagement or inattention linked with age or academic attainment, relative to what is expected of primary-school aged children in the UK?

Method

Rationale

The rationale for adopting this specific research methodology is based on the aims of investigating how primary school aged children deploy attentional processes during their classroom activities, whether this can infer engagement and whether this it is a valid way to do so. Consequently, primary school aged children will be required to wear eye-tracking glasses during classroom instruction. This is the most appropriate measure of eye gaze, given that it is a mobile device that is relatively unobtrusive to the wearer, and even in a short space of time can provide rich, extensive data on the wearer's eye movements using video-based eye-tracking technology (Blignaut, et al, 2014).

The video recordings will inform the researcher directly where the wearers fixated their gaze at any point within the recording. Information relating to the spatial location of school-children's gaze will be used to identify the common targets of fixation within the classroom environment, and how patterns of gaze change dependent on the tasks required of the children during their recordings.

Moreover, the research is also interested in investigating links between individual characteristics and patterns of eye gaze, at this stage of children's developmental trajectories. Therefore the age, gender and assessed attainment levels for mathematics and literacy skills will be taken from the participants directly involved in the research. Average attainment levels for children of this age are established in concordance with the current National Curriculum standards. Government documentation states that most children are expected to progress by approximately one level every two years and by Key Stage Two should be achieving what is defined as level four across all of the tested subjects (literacy, numeracy and science) (Department of Education, 2013). By these standards, it is reasonable to suggest that children recorded to be working at level three are performing below average compared to peers their age, and children working at level five and higher are achieving above average.

Therefore, this research project is hoping to bring together innovative research methods with well-established theories, and to branch out into the field of education by empirically observing patterns of visual attention in a classroom environment. The researcher hopes to investigate whether indicators of visual attention in the form of eye movements can serve as a predictor of academic engagement in the short term, and eventually of later academic outcomes.

Participants

Nine primary school-aged children (five males) with the mean age of ten years and three months were recruited from a primary school in the York district, where participants were selected to be directly involved in the collection of eye-tracking data. Convenience sampling was used to recruit participants, and this occurred by selecting from a sample pool consisting of children in the classroom whose parents or guardian had given consent for their children to be involved in the research. Parents gave their ethical consent for their children to take part, and basic demographic information relevant for the study such as age and standardised attainment levels was collected. Parents whose children were not directly involved in the data collection were also informed that their child might be present in some of the footage collected by the eye-tracking equipment, but that the footage would be encrypted and any images would not be seen by anyone other than the researcher. The children were offered no tangible rewards for their participation, but they did receive a presentation from the researcher about the process and benefits of further education, and some basic information about psychological research as a means of briefing them about the research purposes.

In total, nine participants were involved in the initial collection of gaze fixation data. However, due to the quality of the data collected for two of the participants not being high enough for analysis, their data was excluded from the final analysis. Their omission was due to malfunction of the calibration equipment used in conjunction with the eye tracker, where the malfunction meant that the accuracy of the eye gaze data was below the optimum level necessary for analysis. Problems with calibration become an issue especially because the accuracy of the recordings from mobile eye-trackers is already known to be much lower than static eye-trackers (Blignaut et al, 2014), based on the fact that the frequency of images recorded is much lower than that for static eye-trackers. Therefore, the final data sample for analysis purposes consists of seven participants in total. The age, gender and other relevant demographic details about the seven participants are displayed in Table 1.

Table 1

A table displaying the demographic information of each participant involved in data analysis, including their school year (UK system) and rating of academic attainment in the core topics, literacy and numeracy, based on National Curriculum standards.

Participant	Gender	Chronological Age (in years and months)	Academic Year	Literacy Attainment	Numeracy Attainment	Subject during Recording
1	Male	11.2	6	Average	Average	Literacy
2	Male	10.8	6	Low	Average	Numeracy
3	Female	10.6	6	Average	Average	Numeracy
4	Male	11.1	6	High	High	Literacy
5	Female	9.10	5	Low	Low	Numeracy
6	Female	10.7	6	High	High	Literacy
7	Male	10.0	5	Low	High	Literacy

Apparatus

For the collection of eye movement data, the Tobii Glasses 1 Eye Tracker was used. This device uses the popular and dominant video-based method for tracking eye movements (Blignaut et al, 2014), where a video camera focuses on one or both eyes to record eye movements. In this case the tracking is monocular and incorporated into a device that resembles glasses (Figure D1, Appendix D). With this system, an infrared light generated by the device is reflected from the eye and sensed by a video camera, labelled as scene camera in the diagram presented in Figure D1, Appendix D, and it is important that the reflections are recorded using infrared so as to avoid natural light reflections. This technique is used to estimate points of gaze, where someone looks on a stimulus from an image of the eye and this is based on the tracking of the eye’s pupil and corneal reflection. Whilst the pupil is part of the eye, the corneal reflection is caused by the infrared light source positioned on the device. The information is then analysed to extract eye rotations from changes in these reflections from, in this case just one of the eyes. Basically, the operation to determine where someone is looking is based on three main blocks of activity: image acquisition; image analysis and gaze estimation. In the acquisition stage, images of the eye are grabbed from the camera for later analysis, and the overall goal of image analysis is to robustly detect the pupil and corneal reflection in order to calculate their geometric centres, and the changing distance between the two points as eye movements occur.

The device is able to record individual clips lasting 70 minutes. The data combines video and audio data representing where the wearer is visually focusing, and this is known as point of gaze (POG) tracking. The POG is represented by a series of dots (see Figure 1) that denote the changes in direction of the eye.

For this research, the Tobii system provided the option to use IR markers. IR markers are used to define what are known as Areas of Analysis (AOAs) for automated data aggregations (Tobii Technology AB, 2010). This technique make it possible to obtain visualisations and statistics from the eye-tracking data that is collected. Attached to the Tobii eye-tracking glasses is the recording assistant, which is a small device that records and stores the eye-tracking data before it is transferred to Tobii Studio, the software specifically designed for use in conjunction with the Tobii device for analysing gaze data.

The glasses are very adaptable to every day environments due to the fact they are worn like normal glasses, and are designed to be as comfortable as possible for the wearer. Interference with the data collection will occur if the glass and the sensors are touched or tampered with in any way. It is also stated that the glasses should not be removed during a recording and before the calibration procedure has been conducted. Calibration in video-based eye-tracking is required to form a mapping between features detected in the eye image and the physical orientation of the eye and/or the position of gaze in the environment (Hammoud, 2008). In this instance, calibration was performed by asking participants to look at a number of predefined positions against a blank space using an infra-red (IR) marker. At each calibration target, the eye tracker detects a number of eye image features and associates their positions in the eye image with positions of the target (Nystrom et al, 2008). For this research, the procedure was performed and approved using system-controlled calibration, based on manufacturer specific algorithms, where specially designed software within the hand-held computer decides whether or not the eye is stably directed towards a calibration target.

Procedure

Once ethical approval of the study had been obtained from the University of York Department of Education ethics board, data collection could commence. The research aims meant that children under the age of sixteen would be involved, so it was necessary to obtain signed consent from the school’s head teacher to allow the research to go ahead, as well as consent from any other staff members from the school who were directly involved in the research. The final stage before conducting the research was obtaining consent from parents of any of the targeted children taking part. In order to fulfil each of these requirements, the researcher referred some carefully prepared information sheets about the research, one designed for the school staff (Appendix A), parents (Appendix B) and an information sheet designed specifically with the children in mind (Appendix C). Along with the parents’ information sheet, a consent form was attached (Appendix B) and parents were asked to sign and return to the class teacher if they consented for their child to be involved in the research. This kind of approach is known as “opting-in”, where those who return the forms can be directly involved in the research and the ones who do not will not be involved. However, due to the nature of the research methods adopted, it was imperative that the parents were aware their child might become a passive participant, in the way they could be identified in video recordings. The information sheet clearly stated that the researcher would take the necessary steps to ensure that all of the children involved in the recording, either directly or indirectly would remain anonymous. This was done by encrypting any device that the footage is and will be stored on, and also only the names of those who are directly involved in data collection will be known but these are later numbered to protect identity.

Data collection took place in a classroom, and over the three days of data collection 26 children were present. Out of these 26 pupils, 21 had obtained ethical consent from their parents to be involved in the data collection. However, due to equipment availability and time constraints, we could only obtain recordings from nine of the pupils. These nine pupils were selected from a list devised from those who consented, with the only criteria being that there was an even distribution of males and females involved in the data collection. In this respect, this was convenience sampling since random sampling implies that every member of a population has an equal chance of being selected (Wilkinson, 1999).

Before any data collection occurred, one of the conditions stated in the information sheet was that the researcher provided a short talk as a means of briefing the class about the research. Further, this short talk also covered incentives for pursuing further study and some background knowledge about the research question and psychology in general. Once this had been completed, data collection commenced. Three participants’ recordings took place during mathematics instruction, and five during literacy instruction. Although from completely different fields, the nature of the instruction was quite similar in that there was the opportunity to observe a range of classroom activities, such as participants being directly addressed by their class teacher and also engaging in discussion with their peers.

Each participant experienced the same process, where at first the mobile-eye-tracking equipment had to be calibrated. Calibration is an extremely important component of the eye movement measurement process, as it is one of the factors that ensures better data quality by Nystrom, Andersson, Holmqvist and van de Weijer (2012). This is a relatively unobtrusive procedure, and it provided some time for the children chosen for data collection to get comfortable with wearing the eye tracker glasses before the recording begun. Once the calibration procedure was completed to a sufficient standard, the wearer of the glasses returned to their classroom seat, closely followed by the researcher with the hand held computer. Participants were informed that they were to wear the glasses for twenty minutes during class time, and that the researcher would come and collect them once the time had passed. Participants were also informed during this time not to interfere with any of the buttons on the hand held computer, and also that they could opt out of the data collection at any stage during recording if they wished to do so, by alerting the researcher. Once twenty minutes of classroom footage had been recorded, the researcher collected the eye-tracking equipment from the current participant, and this procedure was adopted for all participants.

Analysis

Before the process of analysing the data could take place, it was necessary to develop a coding scheme with the purpose of identifying the targets of children’s eye gaze within the classroom and operationalising these targets into categories that define whether the children are paying attention or not. Attention, or engagement is often operationalised as a construct by referring to whether those being observed are ‘on’ or ‘off-task’, dependent on the task they have been designated to perform. In this case, ‘on-task’ behaviour is often used as a proxy for engagement in classroom environments (Gill & Remedios, 2012). It is potentially problematic when operationalising what might be deemed as ‘on-task’ in the classroom, as it is dependent on the activity. Therefore, Gill and Remedios (2012) suggest that it is important for researchers to only choose those specific behaviours that are conducive to the type of learning that is taking place at any one time. When operationalising this sort of construct, previous educational researchers relied on observations of classroom behaviour, which is a limited technique, as its reliability is influenced by all sorts of observer variables such as positioning, or the ability to focus on only a small proportion of pupil behaviour at any one time. However, the progression towards the application of video and audio recording equipment in observational research allowed for much wider observations of both physical and verbal interactions.

For this research, the application of video based eye-tracking meant that eye-tracking measures were employed with the impression that they would serve as a proxy for levels of attention, and in order to do so, the device also recorded video clips that captured the surroundings in which the deployment of eye movements occurred. Using Tobii Studio, the recorded glasses data was presented using a function within the software named 'Raw Fixation Filter', which means that the gaze overlay will show all raw gaze data captured by the eye tracker, without any filtering at a 30Hz sampling rate (30 images per second). As this tool allows the researcher to directly observe what the wearer of the eye-tracking glasses have within their visual field in the classroom during playback of the fixation information overlaid with the video and audio footage collected, it also permits the development of a coding scheme for this research project. Since the glasses collect a relatively high amount of data from second to second, in order to code this it was necessary to slow down the recordings to a quarter-speed compared with the real-time footage, which unfortunately compromised the playback of audio footage from the recordings.

Coding Scheme

For each of the seven participants, their observed instruction was divided into periods of either teacher instruction or task-related talk in the form of discussion with peers or evidence of skill transference into pupil's workbooks. After viewing all of the video recordings, six different gaze targets within the classroom were decided on to form a coding scheme, and these were present in all seven participants' clips in the gaze overlay. There were three targets relating to person-based gaze behaviour: 'adjacent peers'; 'distant peers' and ‘teacher’. Three further targets related to physical components of the classroom, known as: ‘own work’; ‘educational environment’ and the general ‘classroom environment’.

When applying the code ‘adjacent peer’, there was an indication from the combination of the video recordings and eye tracker data that the wearer of the glasses gazed at a peer who was either in the seat directly next to, or across from them, where it was the case that pupils were sat on the four edges around square or rectangular tables. With this in mind, the coding of a ‘distant peer’ was defined as a fixation onto anyone out of the range of being classed as an ‘adjacent peer’. For example, this label could refer to peers located further away on the same table as the wearer of the tracking glasses, or peers located at the other side of the classroom. An example of this can be seen in Figure 1, where it is demonstrated that fixations were measured to have occurred on particular points in the wearer’s visual field, who appeared to fixate onto a peer directly opposite them (‘adjacent peer’) and then shifted their gaze towards some peers further away (‘distant peers’).

Thirdly, when instances of gaze fixation were perceived to be in the direction of the class teacher, be it on their face or parts of their body, this gaze behaviour was referred to using the code of ‘teacher.’

The code ‘educational environment’ applied when wearers of the eye-tracking glasses fixated their gaze on aspects of the classroom that were directly related to learning during periods of scholastic activity. For example: if the teacher was using a whiteboard to display scholastic material to the pupils (as in Figure 2), if the teacher was using a projector to present scholastic material, or if the teacher was engaging with interactive resources such as a computer to aid their teaching. When participants fixated on their own academic workbooks during, the code ‘own work’ was applied.

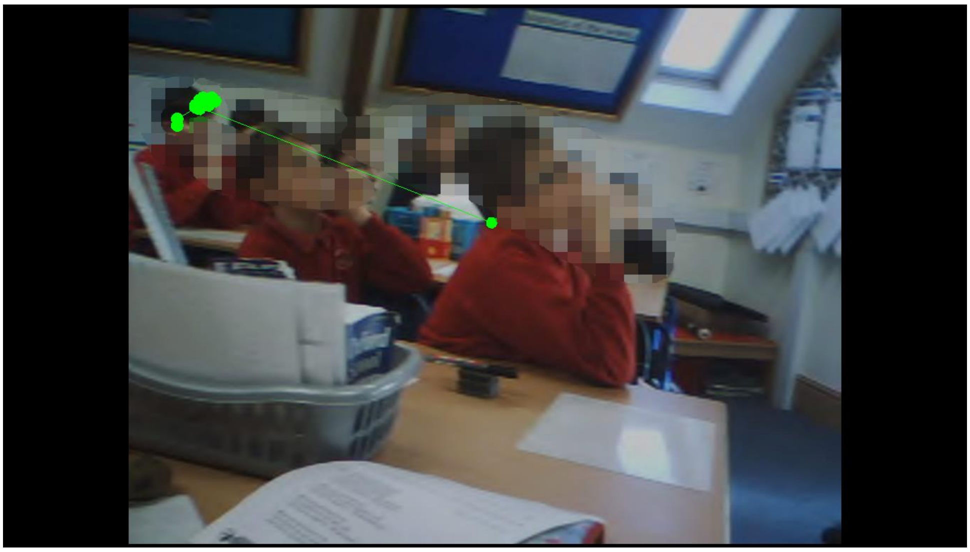

Figure 1. A screenshot of the presentation of gaze-overlay data, combining gaze patterns with video recorded clips. The green dots represent a point of fixation and the line implies movement from one point to another, where the larger dot is present (faces pixelated to preserve anonymity).

Alternatively, if instances occurred where pupils wearing the eye tracker device fixated their gaze onto anything around the classroom that was not directly related to the task expected of them, this was defined as an 'environment' gaze behaviour. Examples in this particular classroom could have been windows, doors, wall displays and different types of furnishings within the classroom. Whether individual occurrences of the six categories of gaze behaviour were classed as 'on-task' or 'off-task' was dependent on the type of educational activities the wearer of the eye tracker was involved in throughout their recording.

Furthermore, the identification of a 'discussion' period in the classroom was classified as segments of time within the recordings where a number of situations occurred relating to task-related talking, these were: when the teacher encouraged short discussions with peers about the content addressed during teaching; when pupils worked together with their 'adjacent peers' to complete an activity, under the guidance of the teacher, or when the wearer of the eye tracker glasses actively engaged in discussion with the teacher when the rest of the class were engaged in some task-related talk. Recording occurrences of the specific gaze behaviours occurred only when children were explicitly discussing the content that had been addressed by the teacher, and this was made possible due to the fact that the glasses recorded audio data as well.

Figure 2. A screenshot of the Tobii Studio presentation of gaze-overlay data, combining gaze patterns with video recorded clips. The green dots represent a point of fixation and the line implies movement from one point to another, where the larger dot is present.

The categories that are indicative of pupils being 'on-task' during periods of 'classroom discussion' can be seen in Table 2, with the rationale for this being that it can be expected that pupils will engage with peers close to them during task-related talk (Gillies, 2003). They may also engage with the classroom teacher for assistance and further discussion, or refer to scholastic resources and their own academic work. Conversely, if a pupil is seen to be looking around the room, fixating on peers that are located far away from them or aspects of the environment not related to learning then these gaze behaviours are termed as 'off-task' during periods of 'classroom discussion' within the recordings.

Moreover, the identification of an 'instruction' period in the classroom was based on the observation of segments of time within the recordings where the class teacher was directly addressing the pupils by way of relaying scholastic content, be this referring to additional resources such as a whiteboard or computer screen or just talking to the whole class.

Recording occurrences of the specific gaze behaviours occurred only when the classroom was silent but for the voice of the class teacher relaying scholastic information to the pupils.

Table 2

A table defining the categorisation of eye movement targets based on whether they were 'on' or 'off' task during 'classroom discussion' periods.

	'On-Task'	'Off-Task'
Gaze Target Category	Peers (Adjacent)	Peers (Distant)
	Teacher	Environment
	Educational Environment	
	Own Work	

The categories that are indicative of pupils being 'on-task' during periods of classroom instruction can be seen in Table 3, with the rationale for these being that the pupils will be encouraged to maintain their attention on the source of the scholastic information being presented, whether this is being addressed by the class teacher or being asked to consult different academic resources that the teacher may be using as teaching aids. Again, if pupils are seen to be looking around the room, fixating on their peers that are located far away from them or in this case close to them (peers (adjacent)), or fixating on other aspects of their environment not directly related to classroom instruction then these gaze-behaviours are termed as 'off-task'.

In order to interpret the tracker data collected from each of the participants, after each gaze-overlay video had been coded using the discussed coding scheme, the data was converted using a function available with Tobii Studio into individual databases using Microsoft Office Excel software. It was most appropriate for this research to adopt temporal measures of data analysis, so within each individuals' file the data consisted of a series of timestamps documenting when instances of a particular event were observed and how long for (in Ms)

Table 3

A table defining the categorisation of eye movement targets based on whether they were ‘on’ or ‘off’ task during ‘teacher instruction*’ periods.*

	‘On-Task’	‘Off-task’
Behaviour Category	Teacher	Peers (Distant)
	Educational Environment	Environment
	Own Work	Peers (Adjacent)

within the 20 minute timeframe. For each of the files, it was also possible to obtain information stating when periods of discussion and instruction occurred within the recording, and in turn whether the instances of gaze behaviour were ‘on’ or ‘off-task’ based on the use of these timestamp periods. With this information available for all participants, the individual datasets were analysed with the research questions considered. The methods adopted will be discussed in detail in the *Results* section.

Results

Introduction

In order to understand how the collection of eye-tracking data can inform the deployment of visual attention in the classroom, each participant's dataset was analysed on an individual basis, and then compared at group level. The presentation of the results will be as follows: the first section will relay the chief findings from descriptive statistical analysis. Relating back to the initial research questions, there will be some focus on results obtained about the effect of the covariate (classroom event) on the duration of participants' gaze fixation towards the six predefined targets ('educational environment', 'environment', 'own work', 'adjacent peers', 'distant peers and 'teacher') in the classroom. Additionally, the frequency of fixations onto the specified targets will be reported. This section will also convey the results of a technique used to count the frequency of switches between 'on'- to 'off-task' behaviour and vice versa. This technique is known as computing a 'time lag'. The 'lag' function is often used in time series analyses to indicate how many adjacent values there are present in a series from a previously specified vector, thus providing the means to investigate how many times the information obtained from each participant's eye gaze data inferred changes between targets of fixation and therefore attention; the rationale for this will be explained further in the allocated section for 'lag' data results.

The following section reports the results obtained from inferential statistics using individual-level data sets. The techniques are applied to facilitate understanding of the data that extends beyond the immediate data alone, as presented in the previous section. Therefore, the potential effect of the covariate on participant's responses was investigated. As the datasets compiled for each participant are non-parametric in nature, it was deemed most appropriate to compute a chi-square statistic which is used to infer whether there is a relationship between the covariates and outcome variable, based on the comparison of frequencies that are observed in certain categories (gaze targets) to the frequencies that might be expected to occur by chance. Owing to the point that these chi-square values were deemed significant (see Table 10), it was imperative to investigate the effect of the covariate further. Therefore, multinomial logistic regression was applied to predict the likelihood of participants fixating on specific targets based on the classroom event ('teacher instruction' or 'classroom discussion'). This technique is similar to binominal regression, with the purpose of it being to compute the probability of membership of each category of the dependent variable, by comparing multiple groups through a combination of binary logistic regressions. In this case, the outcome variable was gaze fixation target, and the predictor was the classroom activity, divided into 2 categories ('teacher instruction' and 'classroom discussion'). Unfortunately, due to an absence of fixations towards gaze targets recorded during 'discussion' periods, it was not possible to include P3 and P5's data.

The calculation uses a category defined before the computation, in this case one of the outcomes variables (gaze targets) with the purpose being to predict the likelihood of it occurring in either of the classroom events, as the value of one category ('teacher instruction') shifts from '0' to another, or '1' ('classroom discussion'), compared against the other outcome variables.

Descriptive Analysis

The mean age of participants in the study was ten years and three months. For each participant, their recording was coded for instances of gaze towards six predefined targets. It is also important to note that depending on the classroom event that gaze towards a target was identified in, it either qualified as 'on' or 'off' task. Information relating to the duration of fixations and their frequency was collected, and it was found that a strong significant positive correlation existed between duration and frequency, where in this instance as duration increased so did the frequency value (r = .912, N= 41, p < .001), frequency data is presented in Table 4.

Based on the total duration of each participants' gaze data recording, Table 5 presents the percentage of the total that each gaze target accounted for. Of all the participants, four of

Table 4

A table defining the count of gaze fixations towards the six predefined targets out of the total number of fixations counted for each participant.

	Gaze Target												
Participant	Ed Env	% of total	Env	% of total	OW	% of total	A Peer	% of total	D Peer	% of total	Teacher	% of total	Total count
1	97	32.12	51	16.88	13	4.30	16	5.29	76	25.16	49	16.20	302
2	95	37.44	23	7.62	36	14.17	13	5.12	52	20.40	35	13.77	254
3	84	31.34	25	9.32	44	16.4	5	1.86	88	32.83	22	8.20	268
4	79	23.51	53	15.7	44	13.09	44	13.09	84	25	32	9.80	336
5	115	31.68	149	41.04	2	0.55	0	0	64	17.60	33	9.10	363
6	53	28.04	41	21.69	20	10.59	11	5.80	49	25.9	15	7.94	189
7	77	38.70	28	14.07	51	25.6	7	3.52	19	9.55	17	8.54	199

them fixated on aspects of their classroom considered components of their ‘educational environment’ the most.

However this information does not address the potential effect of the covariate on the participants’ endogenous selection of fixation targets. Therefore, Table 5 expresses the proportion of each of the six gaze targets, respective of the total duration of each participant’s recording that consisted of ‘teacher instruction’ activity. The allocation of the two activities: ‘teacher instruction’ and ‘classroom discussion’ for each individual’s recording is expressed in Table 6.

Table 5

Participants' duration of fixations towards the six defined gaze targets (Ms), presented as percentages of the overall total duration of their gaze data recordings (standard deviation presented in parentheses).

	Gaze Target					
Participant	Educational Environment	Environment	Own Work	Adjacent Peers	Distant Peers	Teacher
P01	35.45	15.48	6.82	6.24	25.02	10.98
P02	54.39	5.30	22.22	2.28	14.06	10.39
P03	29.15	6.00	23.29	1.26	27.60	12.70
P04	21.22	15.22	16.24	11.08	31.16	5.08
P05	27.58	55.90	0.49	0	12.43	3.59
P06	24.46	24.82	10.27	5.97	26.99	7.47
P07	38.92	11.34	33.3	2.59	7.00	6.95
Mean	33.02 (11.21)	19.15 (17.50)	16.09 (11.17)	4.90 (3.81)	20.61 (9.27)	8.17 (3.31)

The most important finding from this table is that for all of the participants, a larger proportion of their recordings consisted of classroom activity identified as 'teacher instruction', compared with classroom discussion'. The mean proportion of 'teacher instruction' activity, out of the total duration was 83.11% (*SD* =11.58), and *M* =17.89%, *SD* =11.53, (*N*=7), for 'classroom discussion', respectively. The time accounted for by gaze towards the six different targets within the classroom is presented as proportion values in Table 6.

The ranking of proportions for the participants differs greatly between the six defined gaze targets, but to summarise, five of the participants spent the largest proportion of their recording fixating on aspects of their classroom related to their 'educational environment during 'teacher instruction' (see Table 7). Whilst the remaining two spent the largest proportion of time allocating their gaze towards aspects of their general classroom

Table 6

The percentage of each individual's recording accounted for by two types of classroom activity, 'teacher instruction' and 'classroom discussion', based on the total duration.

Participant	Percentage defined as 'teacher instruction'	Percentage defined as 'classroom discussion'
1	77.04	22.96
2	80.06	19.94
3	100	0
4	63.01	36.99
5	95.81	4.19
6	78.29	21.71
7	87.59	13.41

'environment'. The target which acquired the second highest proportion of gaze fixation for four of the participants was 'distant peers'.

For the participants that allocated the largest proportion of their recording time to their 'environment', their next most attended target was their 'educational environment'. As expected, when taking into account all participants' values, the highest mean proportion calculated for the total duration of gaze towards 'educational environment', followed by 'environment'; 'distant peers'; 'own work'; 'teacher' and then 'adjacent peers'. Incidentally for two of the participants, none of their gaze fixations were directed towards their 'adjacent peers' during 'teacher instruction'.

Out of the 15 minute-long recordings for each participant, on average only 11.53% of the total duration was accounted for by detail categorised as 'classroom discussion', based on the criteria discussed in the *Methods* section. As seen in Table 8, P3's dataset consisted only of gaze fixations recorded during 'classroom instruction', so there are no percentage values to compare between the two classroom activities. However, there is for the remaining six participants, where the findings indicate that the distribution of participants' gaze towards the targets of interest during 'classroom discussion' is different to that previously addressed for 'teacher instruction' periods (see Table 8). Consequently, there was a three-way split between the gaze targets that participants spent the most time directing their gaze towards out of the six targets.

Table 7

*Participants' duration of fixations towards the six defined gaze targets (M*s*) during periods of 'teacher instruction, presented as percentages of the overall total duration of their gaze recordings (standard deviation presented in parentheses.)*

	Gaze Target					
Participant	Educational Environment	Environment	Own Work	Adjacent Peers	Distant Peers	Teacher
1	38.54	19.30	2.73	0.76	26.12	12.54
2	59.47	5.95	10.89	0.81	11.13	11.74
3	29.15	6.00	23.29	1.26	27.60	12.70
4	27.71	16.54	10.59	10.43	27.47	7.26
5	26.44	58.28	0.04	-	11.48	3.75
6	26.78	31.15	10.29	-	23.13	8.65
7	40.78	12.95	30.42	0.97	7.99	6.88
Mean	35.55 (12.05)	21.45 (18.40)	12.60 (10.80)	2.85 (4.83)	19.27 (8.69)	9.07 (3.39)

"On" and "Off"- Task Gaze

The underlying research question being addressed in this study is whether eye-trackers can be used as a measure of academic engagement in scholastic environments. This rests with the premise that engagement can be measured behaviourally, through the direct

Table 8

Participants' duration of fixations towards the six defined gaze targets (Ms) during periods of 'classroom discussion, presented as percentages of the overall total duration of their gaze recordings (standard deviation presented in parentheses).

	Gaze Target					
Participant	Educational Environment	Environment	Own Work	Adjacent Peers	Distant Peers	Teacher
1	25.09	2.65	20.56	24.61	21.32	5.75
2	23.71	1.86	47.18	5.74	18.00	3.49
3	-	-	-	-	-	-
4	10.16	12.96	25.87	12.19	37.44	1.37
5	92.06	0.24	1.81	-	5.87	-
6	16.12	1.96	10.22	27.52	40.96	3.22
7	25.55	-	53.14	13.92	-	7.38
Mean	32.12 (29.98)	3.93 (5.12)	26.46 (20.24)	16.80 (9.05)	24.72 (14.47)	4.24 (2.34)

observation of pupils' behaviour in that setting. Often, pupils' observed behaviour is coded as either 'on' or 'off –task depending on the activity they are involved in at the time of observation. In the present study, it is known that there are two classroom activities 'teacher instruction' and 'classroom discussion', this regulates the labelling of individual fixations as either 'on' or 'off' task (see Table 2 and Table 3). With this in mind, it was possible to calculate the duration that each participant spent on and 'off-task' during their whole recording (Figure 3), and during their periods of instruction and discussion, respectively.

In summary of Figure 3, six of the participants exhibited more 'on-task' gaze than gaze towards targets considered 'off-task' (Figure 3); this was not the case for P4, who was found to be more 'off-task' than 'on' overall.

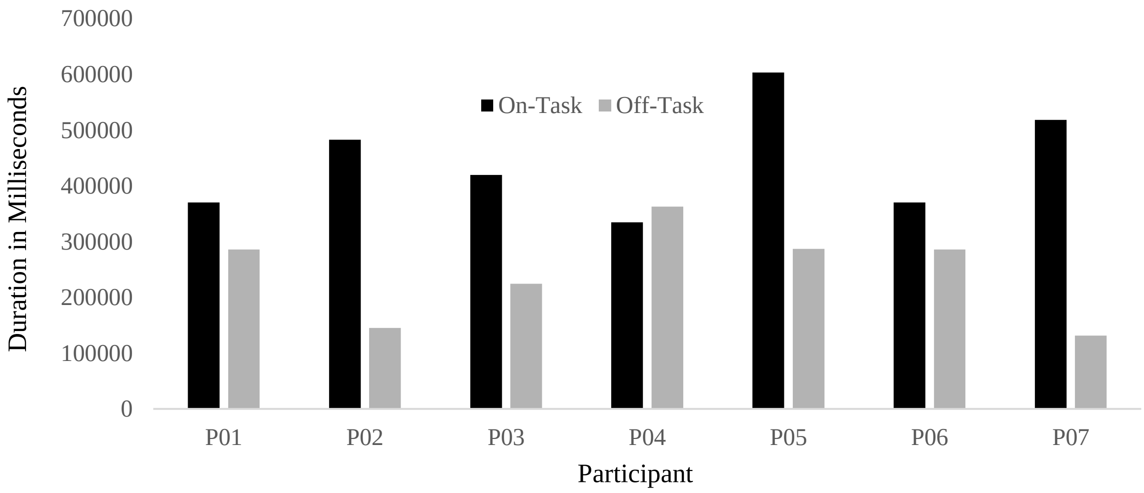

Figure 3. The overall total duration of ‘on’ and ‘off’ task behaviour recorded for each participant (‘teacher instruction’ and ‘classroom discussion’) (in *M*s).

Of interest is whether this finding is consistent when the overall duration totals are divided between the two forms of classroom activity, ‘teacher instruction’ and ‘classroom discussion’. This information has been graphically portrayed in Figure 4 and Figure 5.

The findings indicate that the majority of participants fixed their gaze on targets regarded as being ‘on-task’ the most during ‘teacher instruction’, whereas two of the participants directed their gaze towards targets regarded as ‘off-task’ the most. Additionally, referring to Figure 4, the biggest difference between the two types of behaviour classification can be seen for P2 and P7, with the smallest being observed between P1, P4, P5 and P6.

In comparison, Figure 5 expresses that during ‘classroom discussion’ all of the participants fixed their gaze on targets regarded as being ‘on-task’ more than those regarded ‘off-task’. This means that despite expressing more ‘off-task’ type gaze during ‘teacher instruction’, P4 and P6 exhibit a longer duration total amount of ‘on-task’ gaze. The largest difference between the two types of behaviour classification can be observed in this Figure 5 for P7.

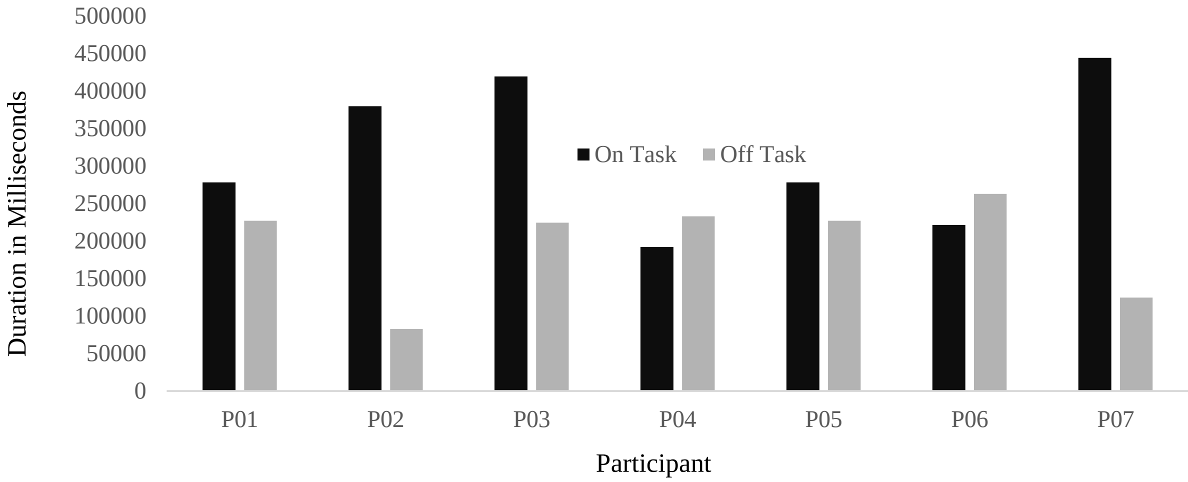

Figure 4. The total duration of fixation towards ‘on’ and ‘off’ task targets for each participant during periods of ‘teacher instruction’ (in *M*s).

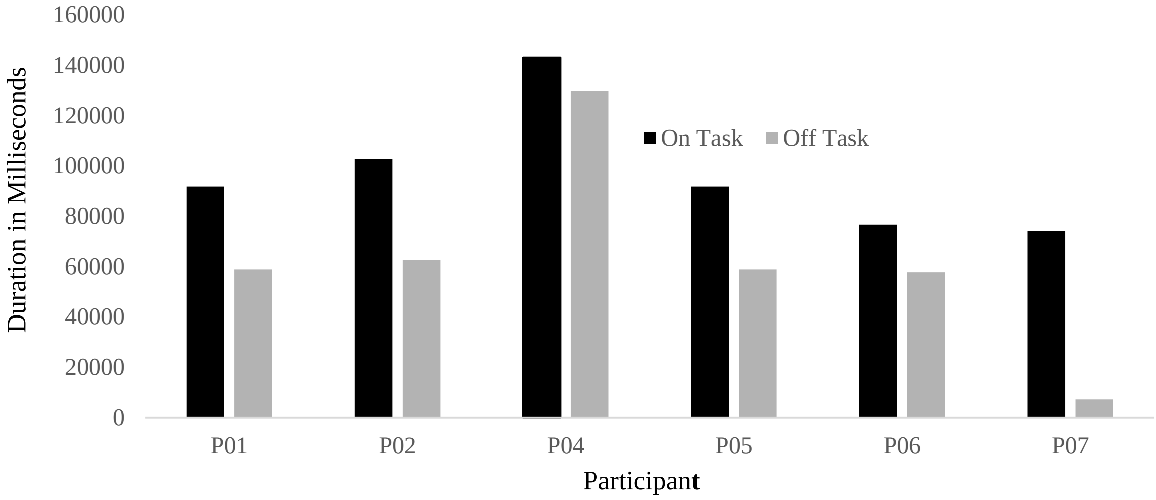

Figure 5. The total duration of fixation towards ‘on’ and ‘off’ task targets recorded for each participant during periods of ‘classroom discussion’ (in *M*s).

Summary

As the results from the initial descriptive analysis suggest, the format of classroom activity did have some effect on the proportion of time participants spent directing their gaze towards different targets in the classroom, predefined by the researcher. For these primary school children, the results state that during ‘teacher instruction’, more of them directed their gaze towards their ‘educational environment’, but during ‘classroom discussion’ the proportions of gaze based on total durations spent attending to each of the six defined categories presented a heterogeneous profile.

During 'teacher instruction', it was found that a larger majority of the participants directed their gaze towards targets considered 'on-task' given the context they were recorded in. As discussed, two of the participants were found to have directed more their gaze during their individual recordings towards targets 'off-task' during instruction. However, during 'classroom discussion', the results imply that all participants spent a longer duration of their recordings directing their gaze towards aspects of the classroom regarded as being 'on-task', compared to 'off-task' targets. These results can be summarised with the point that the participants are generally exhibiting more 'on-task' gaze compared to 'off-task', irrespective of the classroom activity.

Lag Analysis

Therefore, as a means of investigating how much each participant portrayed switches in attention between 'on-task' to 'off-task' type behaviour and vice versa, it was necessary to calculate the total "lag" score. This was done by counting how many times the "0" value representing targets regarded as 'on-task' switched to "1" (representing 'off-task' gaze behaviours) and how many times it switched from "1" to "0". For example, in a sequence of numbers "001011001101010" there are a total of 10 switches. This took into account the difference between the two classroom events in criteria when considering which of the gaze behaviours were 'on' and 'off' task in each of the categories, see Table 2 and 3.

Each participant had around 15 minutes of their eye gaze during class time recorded, and as previously discussed, the areas within the classroom that they fixated on were coded into 6 individual categories. These 6 categories were classified as on or 'off-task', depending on during which classroom event (instruction or discussion) they occurred. In order to develop a measure for shifts in attention over time, the amount of shifts from on to 'off-task' and vice versa were counted per each minute of an individual's recording.

Minute-by-Minute Analysis

The means per each minute of recording was calculated, and presented in Figure 6. The graph indicates that the number of switches between tasks peaks between four to five minutes (*M*= 16.43, *SD*=10.03), before levelling off after around eight minutes of recording, where the mean signifies that there were around nine to eleven switches in tasks per minute for approximately the last seven minutes (‘8’: *M* = 9.43, *SD* = 5.56); (‘9’: *M* = 10.29, *SD* = 4.20); (‘10’: *M* = 11.14, *SD* = 6.01); (‘11’: *M* = 11.29, *SD* = 4.19); (‘12’: *M* = 11.57, *SD* = 9.33); (‘13’: *M* =11.71, *SD* = 8.67) and (‘14’: *M* = 9.71, *SD* = 6.31). The standard deviation values seen in Figure 6 suggest a large amount of variability within the sample, and high variability makes it difficult to see any patterns within the data (Gravetter & Wallnau, 2009). There is always a risk of this when there are too few data points to form a normal distribution.

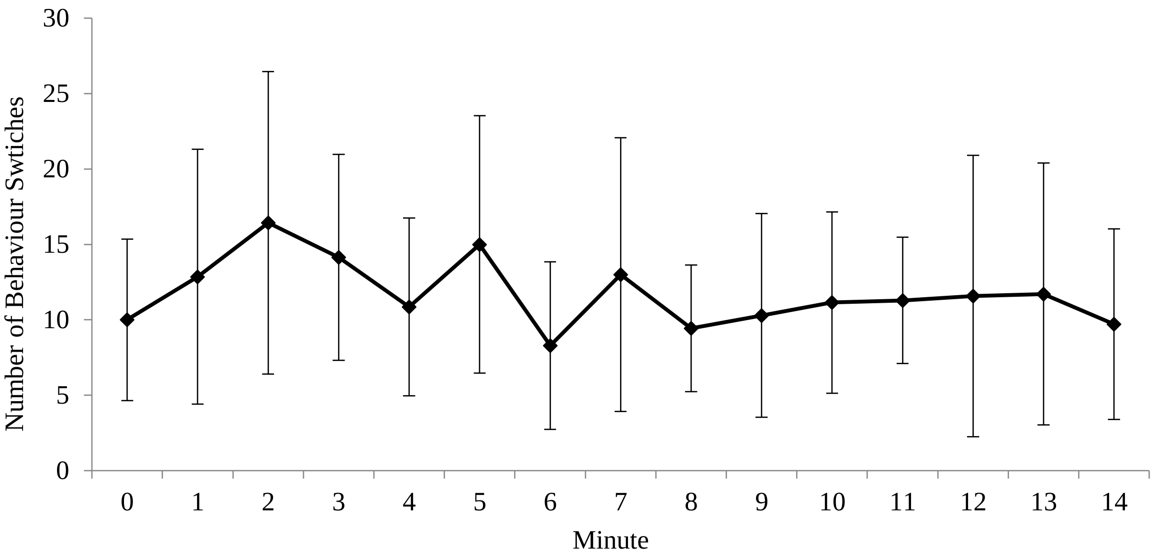

Figure 6. The mean number of switches between ‘on’ and ‘off’ task gaze behaviour, and vice versa per minute of fifteen minute clips of fixation data selected for analysis. The points represent minute-by-minute breakdowns, where ‘0’ refers to a period pertaining to 0 ≤ 0:00:59 seconds of the video clip, ‘1’ to 1 ≤0:01:59 seconds, ‘2’ to 2 ≤0:02:59 etc.

Participant Analysis

Also of interest are the individual values implying switches between tasks, based on the number of shifts in gaze fixation between 'on' to 'off' task targets and vice versa, counted per minute of participants' recording. Participant means can be seen in Table 9. The range of mean shifts in fixation counted is 6.07- 16.67 per minute. The mean number of shifts between participants is as follows, (M= 11.71, SD=3.54). When considering this value, all participant means are within at least two standard deviations of the overall mean. Furthermore, three of the participants scored a mean number of switches in task per minute that was lower than the overall mean, and the remaining four participants exceeded it.

Additionally, based on the information already collected on the total frequency of all gaze behaviours (see Table 4), it was possible to calculate the proportion of gaze behaviours measured that were deemed switches in attention, behaviourally defined as a switch between on to 'off-task' behaviour and vice versa. P6 exhibited the highest proportion of 'distraction' behaviours (79.8%) out of their total amount of recorded behaviours; followed by P1 and P5 (68.87%); then P3 (67.53%); P4 (62.5%), P2 (54.72%) and P7 (45.27%).

Table 9

Mean shifts in attention between 'on' to 'off-task' and vice versa per minute for each participant (standard deviation presented in parentheses).

Participant	Mean
1	13.87 (5.53)
2	9.27 (5.95)
3	12.07 (10.44)
4	14 (4.55)
5	16.67 (6.26)
6	10.07 (5.35)
7	6.07 (5.27)

Inferential Statistics

Pearson's Chi-Square

The frequency of fixation of gaze towards the six predefined gaze behaviours for all participants is presented in Table 5, with the proportion of the total number also displayed. The most common technique for analysis of frequency data is a test known as the calculation of the chi-square statistic, which uses sample data to test hypotheses about the shape or proportions of a sample distribution, therefore this test determines how well the obtained sample proportions fit the population proportions specified by a null hypothesis (Gravetter & Wallnau, 2009). For this specific data set a chi-square test of goodness-of-fit was performed to determine whether the enforced independent variable (classroom event) had a significant effect on the gaze target attended to, by measuring how the observed distribution of data fits with distribution that is expected if the two variables are truly independent.

For all participants, a Pearson's chi-square statistic was calculated, and as seen in Table 10 these values were all significant. This means that the enforced independent variable, in this case the covariate known as classroom activity ('teacher instruction' or 'classroom discussion'), did have a significant effect on the dependent variable, which was the targets of gaze fixation attended to during participant's individual recordings. The significant p-values confirm this statement.

Multinomial Logistic Regression

In the first instance, the base category used for the five individual sets of regression calculations was 'educational environment'. Additionally, new chi-square values were calculated in order to assess whether our model as a whole fits significantly better than an empty model with no predictors. A significant result can be interpreted as the application of the model fitting significantly better than an empty model with no predictors. These values are presented in Table 11. Additionally, Nagelkerke's R^2 was calculated as a measure of

Table 10

Chi-square statistic calculation values for each participant, examining the effect of the type of classroom activity on gaze targets attended to.

Participant	χ^2	Degrees of Freedom	Number of Data Points	*p*-value
1	42.07	5	302	<.001
2	20.48	5	254	<.001
3	**	**	**	**
4	27.01	5	336	<.001
5	48.19	4	363	<.001
6	50.67	5	189	<.001
7	20.61	5	199	<.001

** No chi-square statistic was calculated for P3 as the classroom event was constant (only gaze behaviour during instruction was recorded).

effect size, and this is regarded as a more reliable measure of the relationship between predictor and outcome variables in regression analyses.As seen in table 10, for the participants involved in the regression analysis, all results were found to be significant. The highest value was found to be R^2=.247, which indicated a small-to-moderate relationship of 24.7% between the predictors and the prediction. This suggests that for almost a quarter of the occasions that a fixation towards a particular target was counted, this could be predicted based on which classroom activity (‘teacher instruction’ or ‘classroom discussion’ it was performed during.

Multinomial regression assists with the prediction of the occurrence of fixation onto specific gaze targets in the classroom, based on the known frequencies of occurrences across the two categories known as instruction and discussion. As stated previously, instruction was recoded into ‘0’ and its counterpart, discussion was recoded into ‘1’.

Table 11

The chi-square values calculated to evaluate the fit of the model to the outcome variables in the multinomial logistic regression calculations performed for each participant.

Participant	χ^2	Degrees of Freedom	*p*-Value	Nagelkerkes R^2
1	34.95	5	<.001	.118
2	19.48	5	.002	.077
3	-	-	-	-
4	28.90	5	<.001	.077
5	-	-	-	-
6	53.05	5	<.001	.247
7	26.14	5	<.001	.124

So basically what the analysis highlights is whether there is a significant difference between the two categories of the covariate, when predicting the frequencies of recorded fixations onto gaze targets within the classroom, and the strength of the odds of any difference occurring again.

Educational Environment

The likelihood of each of the five gaze targets being attended to, compared with the reference category of the remaining gaze target ‘educational environment’ was computed for five of the participants. The findings suggest that four of the participants were more likely to attend to targets associated with the category defined as ‘adjacent peers’ during ‘classroom discussion’ than ‘teacher instruction’, compared with ‘educational environment’. P1 *(b*= -2.88, Wald χ^2 (1) = 17.49, p<.001, Exp (B) =.056); P2 *(b*=1.79, Wald χ^2 (1) = 8.27, *p*=.002, Exp (B) =.17); P3 *(b*= -1.35, Wald χ^2 (1) = 11.64, *p*= .001, Exp (B) =.27); P7 *(b*= -1.91, Wald χ^2 (1) = 5.42, *p*=.020, Exp (B) = .15).

Additionally, two of the participants were more likely to attend to targets associated with the category defined as 'own work' during 'classroom discussion' than 'teacher instruction', compared to 'educational environment' P1 (*b*=-1.26, Wald χ^2 (1) = 4.22, p=.040, Exp (B) = 0.28); P2 (*b*= -1.32, Wald χ^2 (1) = 10.02, *p*=.002, Exp (B) =.17).

Environment

The likelihood of each of the five gaze targets being attended to, compared with the reference category of the remaining gaze target 'environment' was computed for five of the participants. For this group of calculations, the findings with the most relevance indicate that three of the participants were more likely to attend to targets associated with the category defined as 'adjacent peers' during 'classroom discussion' than 'teacher instruction', compared with 'environment' as the reference category. P1 (*b*=-3.48, Wald χ^2 (1) = 20.23, *p*<.001, Exp (B) = .031); P2 (*b*= -2.028, Wald χ^2 (1) = 6.55, *p*=.010. Exp (B) =.13) and P4 (*b*= -1.301, Wald χ^2 (1) = 9.13, *p*=.003, Exp (B) =.27).

Two of the participants were found more likely to fixate their gaze on targets associated with the category of 'own work' during discussion than instruction, with 'environment' as the reference category: P1 (*b*=-1.86, Wald χ^2 (1) = 6.947, p=.008, Exp (B) = 0.06) and P2 (*b*= -1.59, Wald χ^2 (1) = 5.87, *p*=.015, Exp (B) = .21).

Also of interest is also the fact that one of the participants analysed showed the complete opposite result to the aforementioned one, where they were found to be more likely to fixate their gaze on the target 'own work' during 'teacher instruction' than 'discussion' compared to 'environment': P6 (*b*= 2.57, Wald χ^2 (1) = 1.648, *p*=.003, Exp (B) = 13.00).

Own Work

The likelihood of each of the five gaze targets being attended to, compared with the reference category of the remaining gaze target 'own work' was computed for five of the participants. For this set of regression computations, For example, three of the participants were found to be more likely to fixate their gaze towards the target of 'teacher' during 'instruction', compared to 'classroom discussion' when cross-referenced with the selected category for comparison ('own work'): P1 (b = 1.64, Wald χ^2 (1) = 5.63, p=.018, Exp (B) = 5.14); P2 (b =1.39, Wald χ^2 (1) = 6.63, p= .010, Exp (B) = 4.00); and P4 (b =2.09, Wald χ^2 (1) = 9.47, p=.002, Exp (B) = 8.06).

This pattern also followed for 'educational environment': P1 (b= 1.26, Wald χ^2 (1) = 4.22, p=.040, Exp (B) = 3.52) and P2 (b=1.32, Wald χ^2 (1) = 10.02, p=.002, Exp (B) = 3.76); and 'environment' for two of the participants: P1 (b= 1.86, Wald χ^2 (1) = 6.95, p= .008, Exp (B) = 6.41) and P2 (b=1.59, Wald χ^2 (1) = 5.87, p=.015, Exp (B) = 4.75), where fixation on these targets was predicted as being more likely during 'teacher instruction'. Once again, the results for P6 present opposing findings, where they were found to be more likely to fixate their gaze towards both their 'educational environment' and 'environment' as targets in the classroom during 'discussion' instead of 'teacher instruction', when compared with the reference category of 'own work': 'educational environment (b= -1.50, Wald χ^2 (1) = 6.03, p= .014, Exp (B)= .223) and 'environment' (b=-2.57, Wald χ^2 (1)= 8.963, p=.003, Exp (B)= .077).

Adjacent Peers

The results indicate that four of the participants were more likely to fixate their gaze towards their 'educational environment' as a target during 'teacher instruction', compared to 'classroom discussion' when cross-referenced with the selected category for comparison ('adjacent peers'): P1 (b= 2.88, Wald χ^2 (1) = 17.42, p<.001, Exp (B) =17.79); P2 (b= 1.79, Wald χ^2 (1) = 8.27, p=.004, Exp (B) =6.60); P4 (b= 1.35, Wald χ^2 (1) = 11.64, p= .001, Exp (B) = 3.87) and P7; (b= 1.91, Wald χ^2 (1)= 5.42, p= .020, Exp (B) = 6.77).

This pattern also followed for the gaze targets 'environment', 'distant peers' and 'teacher'. Out of the participants involved in this part of the analysis, three of them were found to be more likely to direct their gaze to their 'environment' during instruction, instead of discussion: P1 (b= 3.48, Wald χ^2(1) = 20.23, p<.001, Exp (B)= 32.50); P2 (b=2.03, Wald

χ^2 (1) = 6.55, *p*=.010, Exp (B) = 7.60) and P4 (*b*= 1.30, Wald χ^2 (1) = 9.13, *p*= .003, Exp (B) = 3.67). Also, the findings suggest that two of the participants were more likely to direct their gaze towards their 'distant peers', P1 (*b*= 2.79, Wald χ^2 (1) =15.88, *p*<.001, Exp (B) = 16.25) and P4 (*b*=.80, Wald χ^2 (1)= 4.41, *p*=.036, Exp (B) = 2.22), and 'teacher' during 'teacher instruction': P2 (*b*=1.86, Wald χ^2 (1) = 6.84, *p*=.009, Exp (B) =6.40); and P4 (*b*=2.73, Wald χ^2 (1) = 16.09, *p*=<.001, Exp (B) = 15.33), respectively.

Distant Peers

The findings for this set of calculations across participants are highly-variable for this group of calculations, with the only mildly-consistent result being that two of the participants were found to be more likely to direct their gaze towards the target referred to as 'adjacent peers' during 'discussion', compared to 'teacher instruction'. The other significant findings across individuals indicate that gaze towards 'adjacent peers' is more likely during 'classroom discussion' than 'teacher instruction', compared with 'distant peer' gaze: P1 (*b*=-2.79, Wald χ^2 (1) =15.88, *p*<.001, Exp (B) =0.62); P4 (*b*= -.799, Wald χ^2(1)= 4.41, *p*= .036, Exp (B) = .45).

Teacher

The significant results indicated that for three of the participants, gaze towards the targets 'own work': P1 (*b*= -1.64, Wald χ^2 (1) = 5.63, *p*=.018, Exp (B) =.19); P2 (*b*= -1.32, Wald χ^2 (1) = 10.02, *p*=.002, Exp (B) =.27) and P4 (*b*=-2.09, Wald χ^2 (1) =9.47, *p*=.002, Exp (B) = .12), and 'adjacent peers' gaze was found to be more likely during 'classroom discussion', as opposed to 'teacher instruction' when compared with the reference category 'teacher' ('adjacent peers': P1 (*b*= -3.26, Wald χ^2 (1)= 18.4, *p*<.001, Exp (B) =.038); P2 (*b*=-1.79, Wald χ^2(1) = 8.27, *p*=.002, Exp (B) =.17); and P4 (*b*= -2.73, Wald χ^2 (1)= 16.09, *p*<.001, Exp (B) = .065). Additionally, for P4 it was found that all of the other gaze targets ('educational environment'; 'environment' and distant peers) were found to be more likely fixated upon during 'classroom discussion' than 'teacher instruction' compared with the reference category 'teacher': 'educational environment' (*b*=-1.38, Wald χ^2 (1)= 4.43, *p*= .035, Exp (B) =.25); 'environment' (*b*=-1.43, Wald χ^2 (1)= 4.47, *p*=.008, Exp (B) = .24); and 'distant peers' (*b*=-1.93, Wald χ^2 (1), *p*=.003, Exp (B) = .15).

Discussion

Introduction

This research aimed to identify whether head-mounted eye-trackers could be used to measure visual attention to infer the construct of academic engagement in a primary-school classroom. Additionally, this study serves as a pilot for the use of a device that observes the behaviour of the wearer by measuring a specific physiological response, in this case eye movements, and linking them to cognitive processes related to visual attention.

As this study was initially intended to be exploratory, it was not appropriate to consider the effects of independent variables on eye movements. However, it was reasonable to suggest that this form of methodology would provide the opportunity to directly observe the classroom environment from the perspective of the child wearing the head mounted eye tracker, something that to my knowledge has not been conducted in this ever-expanding area of research.

It became apparent after each of the recordings were observed and coded that a covariate existed that was likely to have some effect on the behaviour of the pupils involved in the study and this made the study quasi-experimental in nature. How these variables were defined was addressed in the *Methods* section of this report, with emphasis on the distinctions made between the two conditions when coding individual recordings. With the existence of the covariate, it provided the means to create some research questions relating to how pupils might respond to different pedagogical techniques adopted by their teachers. Based on previous literature, it was suggested that there would be a difference in the duration of different gaze targets attended to between the two classroom activities. It was expected from statistical analysis that there would be longer durations of gaze counted towards targets in the classroom labelled as ‘adjacent peers’ and ‘own work’ during ‘classroom discussion’. Additionally, if children are found to directing their gaze towards relevant targets within the ‘educational environment’, their ‘teacher’ and ‘own work’ during instruction, this implies that they are ‘on-task’ and therefore ‘academically engaged’.

General Findings

Overall, the target that was fixated on for the longest time encompasses aspects of the classroom that adhere to the label of 'educational environment', the gaze target which accounted for on average, *M* =33.02% (*SD*=11.21) of the total duration of participants' fixation data recordings. This initial result implies that the pupils were academically engaged for a substantial period of their time wearing the eye-tracking glasses, irrespective of the differences in classroom activity. When considering the differences between participants, the majority of them directed their gaze towards the target 'educational environment' for the largest proportion of the total duration. However, these results are of little use when addressing the questions posed by the existence of the covariate.

It is also pertinent to mention that when the participants' data was analysed to investigate the amounts of time spent fixating on targets considered both 'on' and 'off' task, depending on which of the two classroom activities they were recorded in. To summarise, most of the participants exhibited more 'on-task' fixations of their gaze, combining totals for both activities at this stage, with only one exhibiting more 'off-task' fixations. The differences between the two classroom activities found will be discussed.

The proportion of recorded footage regarded as 'teacher instruction' and 'classroom discussion' is extremely uneven, as seen in Table 6. This finding was not unexpected, as it was agreed with the classroom teacher that all participants would have their gaze patterns recorded during the first 15 minutes of their lessons, be they literacy or numeracy sessions. Normally, during the initial stages of any lesson, the teacher will spend some time introducing the topic that they are to cover throughout the lesson, by stating the main objectives that they are to address, explaining the relevant vocabulary to the pupils and providing some examples of it in practice (John, 2007), as suggested by National Curriculum strategies. Based on the video recordings collected alongside the eye gaze data, it is fair to say that the approach adopted by the classroom teacher resembled this pedagogical technique. No manipulations of the classroom context were necessary as the aim was to capture the school children's gaze patterns in their naturalistic classroom environment. This explains why for all participants, the largest proportion of their recordings consisted of activity that adhered to the label of 'teacher instruction'.

Gaze Fixation during 'Teacher Instruction'

One of the main aims to be addressed by this study was to investigate whether there are marked differences between the components of their classroom environment that the school-children are likely to attend to, based on which classroom activity they were involved in. The results suggest that most of the participants exhibited more fixations of their gaze towards targets regarded as 'on-task' during 'instruction' with the largest difference between 'on-task' and 'off-task' gaze being found between P2 and P7. The logistic regression results suggest that gaze towards 'educational environment', 'environment', 'distant peers' and 'teacher' was significantly more likely than gaze towards 'adjacent peer' during 'teacher instruction' for most of the participant. This again is in support of the findings from earlier analysis, where duration of gaze towards 'educational environment', 'environment' and 'distant peers' made up the largest proportion out of the total duration for all participants.

Furthermore, findings indicated that most of the pupils directed their gaze towards components of the classroom termed as being part of their 'educational environment' more than any other target, in particular their 'own work' and 'adjacent peers', during 'teacher instruction'. During 'teacher instruction', if school-children are engaged with their 'educational environment' then they are deemed as being 'on-task' or academically engaged. However, when considering the point that the second most attended-to target by a large proportion of participants was 'distant peers' ('off-task') this links with the idea that the development of selective attention can vary between children. The mean age of participants involved in this study was ten years and three months, which is between the ages where selective attention processes should be close to fully functioning (age eight to eleven, according to research by Halperin (1996). As the findings indicate, these children are able to attend to a task that requires their full attention for a prolonged amount of time but they are also subject to being distracted by stimuli that is not necessarily relevant to the task they are involved in at the time (‘teacher instruction’). Therefore, the use of content-heavy introductions to lessons on the whole is a useful pedagogical technique in this case, as most pupils are generally able to remain engaged for the first 15 minutes of their lessons.

As the participants involved in the study demonstrate varying patterns of ability in the core subjects and there are so few of them, it is difficult to link this information when contemplating any explanation for the present findings. However, it is possible to suggest there is a link, based on what is already known from research on the relationship between academic ability, academic attention and the ability to selectively attend successfully. Of note is the point that a small proportion of the participants were found to spend more of their time during ‘teacher instruction’ directing their gaze towards their general ‘classroom environment’, which was regarded as an ‘off-task’ target. Although there is the possibility that the school-children were employing auditory attention to the ‘teacher instruction’ whilst looking elsewhere in the classroom, by nature this constitutes divided attention, as opposed to focussed attention, and this notion supports the defining of targets as ‘off-task’ during their respective classroom activities.

The participants in question were both found to be exceeding the targets defined for them by National Curriculum standards in the assessed core subjects. The fact that these pupils were performing at levels above what was expected of them, compared to peers of the same age suggests that they have enhanced abilities, and can grasp and apply the concepts addressed in the core subjects quickly and successfully. One possible explanation for the ‘high-achievers’ appearing to direct more of their gaze and possibly attention towards ‘off-task’ targets within their classroom, could be linked to a specific line of research on the adaptive and maladaptive functions of the concept of ‘mind wandering’. Mind-wandering is described in cognitive psychology research as the self-generation of thoughts not overtly related to an external goal (Smallwood & Andrews-Hanna, 2012), and whether this is an adaptive or maladaptive process has been intensely contested over the last few years. On the side of the debate that favours mind-wandering as an ‘adaptive’ and wholly normal process, research has suggested that self-generated thought can enhance creativity; help consolidate self-memory and has been linked to a style of long-term decision making (Smallwood & Andrews-Hanna, 2012). Therefore, linking back to this study, it could be suggested that if the pupils are showing signs that they are more intelligent than their peers based on standardised test scores, then the activities they are involved with in the classroom such as application of a concept in an academic domain might be less demanding of their attention, compared with their peers who are performing at or below the level expected of them. This interpretation is based on the idea that ‘mind-wandering’ is much more frequent in undemanding tasks than in demanding tasks, so the children deemed as possessing higher intelligence might be more likely to engage in ‘self-generated thought’, which of course is a construct unmeasurable within this study, but it could be linked with the fact that a small proportion of the children did appear distracted, and therefore engaged in ‘off-task’ mind-wandering.

Following on from this point, it could also be considered that there might be some issues with the operationalisation of the terms ‘on-task’ and ‘off-task’ behaviour within the classroom context. The idea that ‘off-task’ behaviour as a construct has negative connotations in relation to academic engagement has been commonly-accepted in previous research (Gill & Remedios, 2012), but this does not take into account that those who do not appear to be paying attention might already be achieving a higher academic standard than their peers and are able to employ what is known as ‘unfocused’ attention (Fisher et al, 2014), where they appear to be listening to the teacher instruction but can appear ‘off-task’ by focusing on aspects of the classroom other than the educational content relating to the teaching. Therefore, when operationalising ‘off-task’ behaviour in the classroom as a construct in the future, this particular body of research should be taken into account, as the scope of behaviour that can be accessed via observational research methods is broad, and likely to be heavily influenced by factors that are beyond the control of the researcher. For this particular study, the interests were predominantly the potential effect of the classroom environment on gaze fixations made, when there was potentially many other unconsidered factors at an individual-level influencing the outcome of the results.

Gaze Fixation during ‘Classroom Discussion’

On the whole, participants spent their longest duration of recording during ‘classroom discussion’ fixating on targets that were judged as being ‘on-task’, given the nature of the activity (see Figure 5). This total takes into account fixations towards the ‘educational environment’; ‘own work’; ‘adjacent peers’ and the ‘teacher’. One of the participant’s results suggest they spent very little time fixating on targets considered ‘off-task’. The participant in question was one of the youngest involved in the study, and was part of the cohort that was in academic year five, based on their age (fourth grade in the United States) at the time of data collection. There were a number of other participants in year five, and also some in the year above. The small amount of diversity in age between participants and the differences in patterns of gaze fixation across classroom activity provides further testament to the influence of individual differences between the children for the variability in the process of developing conscious attention deployment, which allows children over time to able to focus on the relevant stimuli for what they are currently experiencing, and being able to filter out irrelevant stimuli in a complex world full of objects, people and situations demanding attention.

When evaluating the difference between periods of gaze towards specified targets during ‘classroom discussion’ and comparing this information with the findings reported during ‘teacher instruction’ periods, no target was highlighted as being attended to the most by a larger proportion of the participants. Therefore, during ‘discussion’ the three gaze targets that accounted for the largest amount of time during each of the participant’s recordings are ‘educational environment’, ‘own work’ and ‘distant peers’. Results indicate that ‘educational environment’ is the target most attended to across participant recordings (M=32.12, SD= 39.98), during ‘classroom discussion’. Therefore this indicates that the participants involved in the study were generally found to be more ‘on-task’ than ‘off-task’ during both types of classroom activity.

This conclusion is further supported by the findings from the logistic regression analysis, where for most of the participants the results indicated that gaze directed towards their ‘adjacent peers’ and ‘own work’ was significantly more likely to occur during ‘classroom discussion’ compared with ‘teacher instruction’, and some participants expressed little to no gaze directed towards the target referred to as ‘adjacent peers’ during instruction. It was expected that the pupils would engage with peers close to them during task-related talk, or ‘classroom discussion’. Encouraging task-related talk is part of a pedagogical technique known as ‘cooperative learning’ which is well-documented as having a positive effect on academic outcomes, school-based learning and social skills (Gillies, 2003).

Cooperative learning urges small groups of pupils to work together to facilitate completion of a task relating to the concept being addressed by the classroom teacher, therefore it makes sense to advocate the higher duration and likelihood of gaze towards the target of ‘adjacent peers’ as being ‘on-task’ behaviour, and that these pupils are actively engaged in any of the task-related discussion occurring during their recordings. The fact that the participants engaged with the task-related discussion could be explained by the seating arrangements that had been made by the class teacher, as the class were all seated around small tables, which is said to facilitate pupil discussion (Guardino & Antia, 2012). These tables usually consisted of four to six pupils, a size considered to be useful for pursuing cooperative synthesis tasks, but not effective for overall rote learning (Johnson & Johnson, 1987). However, considering that our results indicate that the children spent a larger proportion of their time engaging with their ‘adjacent peers’, at least visually during ‘discussion’, this implies that task-related talk might have been more likely to occur between a dyadic or even triadic group of pupils. Previous research states that a dyadic grouping could mean that out of the pairing, one pupil assumes the expert role and leads the task related talk, whilst the other pupil assumes the novice role and listens (Light & Perret-

Clermont, 1990). However for this research, the pupils were grouped around the tables based on their current levels of ability in both literacy and numeracy, when these sessions were occurring. Therefore, if a dyadic grouping forms, based on the finding that ‘adjacent peer’ gaze was more common during ‘classroom discussion’ periods, then this is more likely to be described as a mutually naïve dyad due to the perceived similarities in ability, with the positive implications being that groupings of this type are more likely to be effective in open-ended problem solving (Damon & Phelps, 1989) and mind-mapping ideas (Doise & Mugny, 1984).

However, it should also be considered that because no content-analysis of the verbal interactions between pupils and between teacher and pupils was carried out, it is not possible to state whether the pupils were engaged in task-related talk or they were in fact discussing something completely off-topic from the task expected of them, which is always a risk when pupils are left responsible for facilitating their own discussion. Research conducted by Kerry and Sands (1984) substantiates this claim, where they found that the cognitive demands of pupils during task-related discussion were poor, as was the quality of verbal interaction between the pupils. So, if we were to use eye-tracking methodology as a measure of engagement with ‘classroom discussion’ specifically, it would be valuable in future to perform some qualitative content-analysis on the audio footage collected from the video overlays, to pair eye movements with the verbal interactions captured between the pupils and also their teacher.

Switches in Gaze Fixation as a Measure of Attention

One of the main research questions to be addressed by this study was whether the tracking of eye movements could be used as a measure of engagement in a classroom setting. Engagement in this study was, as previously discussed, defined as fixation towards specific targets in the classroom considered as being ‘on-task’ based on the type of activity they were recorded in, therefore disengagement was defined as fixation towards targets that were considered ‘off-task’. This technique provided counts of how many shifts there were of fixation between 'on-task' and 'off-task' targets and vice versa, and the aim of this measure was to highlight distractibility in the participants involved in the study, under the well-established premise that children's attention is usually easily diverted from a current activity to a new event present in their environment. These are commonly referred to as 'distractions' within a child's environment, and as Higgins and Turnure (1984) suggested, many significant impairments found in children's academic performances are attributable to distractions, but it is well documented that distractibility does decrease markedly with age (Higgins & Turnure, 1984).

The classroom provides ample opportunity for distractions to occur due to the busy, vibrant environment that the children are experiencing, however this is not disregarding the benefits of having helpful visual displays around the children. Nevertheless, it was suggested based on previous research that the more shifts between task counted per minute, then the more distractible the school-children were considered to be.

Results from the present study indicate that the number of switches in the placement of gaze between targets based on whether they looking from 'on' to 'off-task' targets or vice versa appear to stabilise after about eight minutes of recorded footage through to the end of the clips. In relation to this finding, it is also important to remember that each participant's 15-minute recording took place at the start of either their numeracy or literacy session, disregarding the first five minutes to allow acclimatisation of the eye-tracking device. Up until the eight minute point, the mean number of switches between tasks per minute is highly-variable, with a large standard deviation score. This could indicate a period of high distractibility occurring at the beginning of sessions, before pupils are able to maintain their focus on the task they are presented with. If the five minutes of the session that was not coded is added to this identified eight minute period, the findings suggest that the children took around thirteen minutes to settle into their lesson, as stated by the point that the mean number of shifts between task type did not normalise until after this period.

Gaze Switches and Implications for Education

There is a significant chunk of the lesson where the children appear to be highly distracted, thus highlighting questions about the duration it takes children of this age to fully concentrate on the scholastic activity they are involved in. This particularly applies to the content-heavy approach which is favoured by the National Curriculum (John, 2007), where the present findings indicate the possibility that a heavy content-based introduction to lessons is not the most appropriate approach. It is generally accepted that the younger children are, then the more difficult they find it to initiate attention and sustain it for considerable amounts of time without becoming distracted (Lopez, Menez & Hernandez-Guzman, 2005). Little research has focussed on the possible effects of sustained attention in educational settings, but as the present study suggests that children are still showing some switches even after 13 minutes, this might be a result of the potential for distractions provided in in such a visually and audibly-salient environment. School-children are more often than not required to switch their attention between multiple components of their classroom, such as their teacher, the learning materials and their peers, as socialisation as well as content-based instruction are both important parts of children's educational and developmental trajectory (Bronfenbrenner, 1979). However, in line with the findings of the study by Fisher et al (2014), these visual distractions could be affecting the levels of academic engagement for pupils and may have some effect on later academic gains, which in light of the present findings, warrants further investigation.

An alternative interpretation of these results is the possible influence of the phenomenon commonly referred to as the Hawthorne effect. This was previously defined in this report as being a problem in research that participants' knowledge that they are in an experiment modifies their behaviour from what it would have been without the knowledge (Adair, 1984). Reportedly, it is even more difficult to identify in studies taking place in naturalistic environments. An attempt to eradicate the possible influence of the Hawthorne effect from this study was described in the *Methods* section of this report, where children wore the eye-tracking glasses for some time before their data actually counted towards the final analysis to allow the novelty of being involved in the research to wear off. The fact that the children did not appear to settle down to their respective scholastic activities until the at least 13 minutes into the session highlights that the effect may have taken longer to wear off than anticipated.

There is little research on the impact of the Hawthorne effect for research conducted in educational settings, but a report published over 50 years from Cook (1962) states that “there is of course in educational experimentation, a so-called Hawthorne effect. It is well known than in an experimental situation teachers and pupils are more highly motivated…” Therefore, there is every chance, with the knowledge that their behaviour was being observed, that both the classroom teacher and pupils did not act as they would normally do in this environment, thus affecting the validity of the findings.

Limitations of the Present Study

Inter-Rater Reliability

Issues with the methodology could have reduced the reliability of the research, one of these being the lack of inter-rater reliability for the coding of the participants’ eye gaze footage based on the pre-established coding system. Inter-rater reliability is a technique often adopted in empirical research, where a number of naïve coders are asked to code data based on a coding scheme provided by the original researchers. Their naivety is important to the process, as they should be unaware of the aims of the research. Unfortunately for this specific project, it was not possible to recruit extra coders to work on the gaze data due to time constraints and the lack of opportunity to offer any incentives for involvement in the coding process. The principal researcher collected, coded and later analysed all the data and despite being the perpetrator of the research questions, the process of coding was conducted with integrity and no manipulation of the coding system once it had been decided on. However, in future. the best possible option to ensure reliability of a coding system is to recruit naïve coders to work on the data sets. Measures such as Cronbach's Alpha would have ensured that the coding decisions were related, thus ensuring that the constructs within the coding system are operationalised.

Issues with Sampling

The underlying issue throughout this report has been the issues with using such a small sample to obtain eye gaze data from. Nine participants in total were directly involved in the data collection process, but only seven of these participants produced data appropriate for analysis. The problems with small samples have been well-documented in research over the years, such as Button et al (2013), stating that a study with low statistical power (small sample) has a reduced chance of detecting a true effect, and also low power massively reduces the chance that a statistically significant result reflects a true effect. So for this particular research, it was found that the type of classroom activity did have a significant effect on the category of gaze target that the children in the sample were likely to attend to, but as the sample is so small it is wholly unrepresentative and cannot be used to infer any ideas about this population's behaviour on a larger scale. If it had been possible to obtain a larger sample for this research, with a total closer to what is usually deemed as a normal distribution in psychological research then it would be possible to relate conclusions to the general population. For the participants that were recruited it was necessary to analyse each participant's recording individually, and with the magnitude of data that was collected from just seven participants, the amount of time it took to code consumed a large proportion of the time allocate to complete this project. If a similar research project were to be conducted in the future, a suggestion would be to increase the sample size and allow more time for any problems that arise along with the data collection process.

Issues with Application of Eye-Tracking Device in the Classroom

An agreement was made with the school involved in the research for the data collection to remain as unobtrusive to the daily-running of the school and classroom in question as possible, so the researcher had access to the classroom for five days in total. Unfortunately, the researcher had access to only one mobile eye-tracking device, so this meant that only one participant could have their eye movements recorded at any one time. For each participant, the eye-tracking device had to be calibrated. Usually, this is a simple process, completed relatively swiftly by most people. However, during the calibration process for each of the children involved in this research, the process took some time to complete in order to ensure that the glasses were accurately tracking the eye movements of the wearer, as the children notably experienced difficulty in overtly directing their gaze towards the IR marker. It became apparent some methodological issues were amounting due to the fact that these glasses were not originally designed to be worn by children, as the frames were large when placed on their faces and this clearly had some effect on the detection of the cornea based on the simple differences in size and stature between children and adults.

An additional issue comes in the form of children's cognitive development, where research has established that the ability to suppress reflexive saccades develops with age, and usually does not mature until children are well into adolescence. In this context, this research implies that children of primary school age, such as those in this study might find it difficult to emit voluntary control over their saccadic eye movements towards a targets, and these might be overridden by reflexive saccades (Fukushima, Hatta & Fukushima, 2000). Therefore, this could explain the difficulties the sample presented with the completion of the calibration process required before the tracking of eye movements could begin.

The issues did not end here unfortunately, as it was expected and previously discussed that the novelty factor of being involved in the research would have some effect on not only the participant's behaviour but those interacting with the participants also. Despite being requested not to do so during their recordings, the researcher observed that participants were prone to fiddling with the device, possibly as a result of discomfort from wearing the glasses or merely just intrigue with the capabilities of the device. The device specification states that wearers should refrain from touching the glasses once they are recording as this interferes with the accuracy of the eye gaze data collected. Realistically, in order to ensure the highest accuracy as possible the device should be recalibrated each time it is tampered with. Unfortunately, in this research context, this was not possible because it would have disrupted the lessons that were being conducted during the recordings. Therefore, it should be taken into account that there are a number of factors likely to influence the accuracy of the collection of data pertaining to the eye movements of the participants, and this is to be expected given that the research honed in on the behaviour of children in the classroom, and were measured using a mobile eye-tracking device which is known to measure eye movements with less accuracy than static eye-trackers.

The accuracy of data obtained when using this technique is a frequently-discussed issue in current research, due to the fact that video-based eye-tracking is the most widely practised eye-gaze methodology. Blignaut et al (2014), stated that discrepancies between the stimuli that is attended to at the beginning of the fixation and the stimuli recorded by the device can occur, and they suggest this is as a result of inaccuracy of the eye tracker or inaccuracy of the participant’s eye movement system. Lack of accuracy is often referred as a series of systematic errors that may result from bad calibrations, too much head movement and other sources strongly dependent on the particular characteristics of individual participants. In this particular research, it was not feasible to recalibrate the mobile eye-tracking device during recording as this would provide disruption not only to the lesson occurring conjunctively, but most importantly it would interrupt participant behaviour when the main aim of the research is to track children’s attention process in their natural learning environment. Blignaut et al (2014), suggest that most of the eye-tracking devices on the market claim to compensate for ‘drift’ created by movement, or in this case fiddling with the device that would otherwise necessitate recalibration. So with this in mind, one must assume that the devices are recording as accurately as possible as long as a strict calibration process has been conducted prior to recording of eye movement data.

Issues with Theoretical Basis for Research

Additionally, there are issues with the concept of linking eye gaze and cognitive processing. Ever since the eye-mind hypothesis proposed that eye movements provided a dynamic trace of where attention is being deployed (Just and Carpenter, 1980), a vast amount of research has been published supporting or disputing this theory. In this particular research, the general idea is that the fixations of gaze infer that at least visual attention is being paid to the stimulus in question, however the theory is often contested. Anderson, Bothell and Douglas (2004) state that eye movements give little information about the underlying retrieval processes controlling the switches in gaze, as the processes are independent from the process controlling retrieval of information relating to the visual input. Therefore, their research findings refined the mind-eye hypothesis, where it is suggested that eye movements do not necessarily represent mental processes but they do reflect ongoing processes to the extent that both processes depend on the encoding of information. In the context of the current research it is important to consider the complexities of the interplay between the complex processes of visual attention and eye movement, but the processes are not at the forefront of the research questions being addressed by this study.

Future Directions

In order to increase the reliability of the research methods, it would be appropriate to provide a secondary measure of attention to cross tabulate with the data obtained from the eye-tracking glasses. Attention rating-scales are self-report measures usually applied in research to give participants the opportunity to rate their own attention abilities, before they are asked to perform tasks that measure attention processes behaviourally. There are a number of inventories that have been developed over the years, such as the Attention-Control Scale (Derryberry & Reed, 2002); the Effortful Control scale (Lonigan & Phillips,

2001) and the Test of Everyday Attention for children (TEA-ch; Manly, Robertson, Anderson & Nimmo-Smith, 1999). Generally, standardised clinical batteries such as these are used for the assessment of selective attention, sustained attention and attentional switching via a range of subtests. Therefore, in conjunction with the use of eye-trackers to measure attention behaviourally, in order to increase the validity of any findings relating to children's attentional deployment, they should be linked up with self-reported levels of attention ability. In the context of this particular study, a battery designed for use with children would be the most appropriate, such as the TEA-ch one as this assesses a number of attentional abilities that can be linked with the investigation into the link between visual attention and academic engagement, in particular, sustained and selective attention. Similarly, there are a number of inventories used to investigate the construct of academic engagement, one of these being the Student Engagement Instrument (SEI) (Appleton, Christenson, Kim & Reschly, 2006). The purpose of measures like these are to focus on the two higher-inference types of student engagement, cognitive and affective via student self-report methods. This measure is usually used alongside a behavioural measure of engagement such as classroom observation, so would be appropriate for use in this research context if something similar were to be conducted in the future. With these examples of psychometric indicators of engagement and attention, patterns of gaze fixation could therefore be linked with participants' profiles as assessed using such a battery and could potentially advocate the reliability of using mobile eye-tracking devices as a measure of academic engagement.

This is one of the main suggestions for taking this study forward if something similar were to be conducted again, but it is also important to consider the possibility of introducing experimental manipulations on the classroom environment and how this might affect the school-children's classroom gaze fixation behaviour, whilst also adopting a micro-measure of learning in the form of a content-based memory test after a session has been taught. For example, the experimenter could make additions to the environment in the form of extra visual displays, or introduce distractions whilst teaching is occurring. Alternatively, the experimenter could remove aspects of the classroom environment, or alter the seating arrangements whilst teaching is occurring. A similar format was adopted in research conducted by Fisher et al (2014), where they also observed the effect of manipulations of the classroom environment, in particular providing sources of potential distraction usually found in classrooms and how these affected children's behaviour and their performance on a content-based memory task after their lessons ended.

Conclusion

To summarise, the purpose of this research was to investigate the feasibility of using a mobile eye-tracking device in a primary school classroom as a measure of academic engagement. Based on the research findings, it can be said that the implementation of the eye tracker was successful in conjunction with the coding system developed to analyse the eye movement data collected. Using this system, it was found that the participants in the study generally fixated their gaze on targets regarded as 'on-task' more so than 'off-task', with a few exceptions found for participants when the results were divided between the two classroom activities. Therefore, the point that there are significant differences between the targets participants fixated their gaze upon that appear to be influenced by the type of classroom activity ('teacher instruction' and 'classroom discussion'), found in both the descriptive and inferential statistical analysis suggests that classroom activity does have some effect on school-children's deployment of attention. Additionally, another of the main findings was the fact that during this study the primary school-aged children collectively took up to thirteen minutes to appear to settle into their lessons, as they all recorded a high amount of switches between gaze fixation targets, thus implying shifts in attention.

Some potential future directions have already been discussed, in the form of additional measures that might be applied if a similar study were to be conducted. Also, issues with methodology and sampling have been considered with suggestions as to how they might be smoothed out in the future. Finally, this project will contribute to the pool of research relating to the application of dynamic measure of eye gaze to naturalistic environments, especially in educational settings. As this was a pilot study, it provides for the development of this type of project. For example, in future studies of this kind, manipulation of the environment to compare gaze patterns between conditions would be beneficial and highly informative. Finally, the study suggests that eye movements may serve as a proxy for academic engagement, by focussing on the idea that eye movements do indeed link with cognitive processing of, in this case, visual attention processes. However, additional measures of the constructs, attention and engagement, should also be applied to further validate the use of this device when implying participants' eye movements link to their levels of engagement in the classroom.

Appendix A

UNIVERSITY of York

Psychology in Education Research Centre,

Department of Education

Informed Consent Form for School Staff

This informed consent form is for the staff working at N***** C of E Primary School, who we are asking to take part in this research project.

Principal Investigator: Emma Campbell (erc519@york.ac.uk)

Supervisor: Professor Robert Klassen

Institution: University of York, Department of Education

UNIVERSITY of York

Psychology in Education Research Centre,

Department of Education

Title of Proposed Study: Attention patterns of primary school aged children in a classroom setting.

Information Sheet for School Staff

My name is Emma Campbell and I am a Master's research student at the University of York, and you or willing members of staff from your school are being invited to be involved in this piece of research. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with other members of staff from your school if you wish. Please contact me if anything is unclear or if you would like more information.

What is the purpose of the study?

The purpose of the study is to investigate eye gaze patterns, or where pupils tend to look during the time in which they spend in the classroom. We would like to establish what effect this may have on a number of different things such as confidence, motivation and whether these patterns have any link to attainment levels.

Why is this school being asked to participate?

We are currently looking for schools to take part in the study and we would like to ask your permission for your pupils to participate. We are seeking to recruit participants from year 5 or year 6. We would like your permission to come into your school and observe some classroom situations through the eyes of the pupils. Therefore, the children that might participate will be asked then to wear a device known Tobii glasses, which are designed to specifically measure eye gaze for a small proportion of one of their lessons. In addition they will be given a test of working memory lasting no longer than fifteen minutes. Also, we will ask you for their name, date of birth and their current level of academic attainment, based on national curriculum standards.

If you agree to take part in this study, we will contact you to arrange a suitable time to come into school and carry out this testing. We would like to assure you that the members of the research team who visit your school will have been checked under DBS procedures. Consent forms will also be provided for parents to complete as no child can take part in the study without parental consent. All the information collected in this study will be kept strictly confidential and also will be kept secure, in an encrypted location. The findings from the data may be used for publication, i.e. for a research report and presentations. Importantly, neither the children's names nor the school name will be recorded on research materials but will instead be replaced and referred to using numbered codes. If at any point after data collection, the school wishes to withdraw its' involvement with the study, the data collected will not be used any further.

We hope that you agree to take part in this research and look forward to having the chance to work with you. If you require more information about the research please don't hesitate to contact me by email at erc519@york.ac.uk. If you would like to participate in the study please complete the consent form below, and return it to me in person or to the school office, where they will be referred on to me. Additionally, **if you have any concerns about the research you may also contact Dr Emma Marsden, chair of the Education Ethics Committee, emma.marsden@york.ac.uk.**

Thanks for your consideration,

Yours Sincerely,

Emma Campbell

Department of Education,

University of York

Heslington Road,

York

YO105DD

Consent:

"Attention patterns of primary school aged children in a classroom setting"

I am aware of the aims and procedures involved in this research and the opportunity for me to enquire further. Also, I understand that participation is voluntary and that I am free to withdraw consent and any child involved at any time at any time during data collection, and up to two weeks after data collection is complete without giving any reason and without there being negative consequences. Furthermore, I understand that the information gained will be anonymous and that the children's names and the school's name will be removed from any materials used by this research in the future.

Signed ………………………………………………………(headteacher/teacher)

Print Name…………………………………………………

Date…………………………………………………………

Appendix B

UNIVERSITY of York

Psychology in Education Research Centre,

Department of Education

Informed Consent form for Parents

This informed consent form is for the parents of children between the ages of 9-11 who attend N***** C. of E Primary School, who we are asking to take part in this research project.

Principal Investigator: Emma Campbell (erc519@york.ac.uk)

Supervisor: Professor Robert Klassen

Institution: University of York, Department of Education

UNIVERSITY of York

Psychology in Education Research Centre,

Department of Education

Title of Proposed Study: Attention patterns of primary school aged children in a classroom setting.

Information Sheet for Parents

N**** S********- B*** of N*** C. of E Primary School has kindly agreed to allow this school to take part in a new project being conducted by researchers from the University of York and your child has been invited to be involved in the research study. Before you decide whether you want to your child to take part, it is important for you to understand why the research is being done and what their participation will involve. Please take time to read the following information carefully, and please contact me if anything is unclear or you would like more information.

Thank you for reading this.

What is the purpose of the study?

The purpose of the study is to investigate eye gaze patterns, or where pupils tend to look during the time in which they spend in the classroom and what effect this may have on a number of different things.

Why might my child be chosen?

Children's ability to pay attention to what they need to is said to be fully developed by middle childhood, so at around nine to eleven years of age. This is why your child's class has been selected to take part in this research. We hope for a number of children to be involved in the research, and based on whether you consent for your child to take part they will be placed on a list with the other children who have obtained consent to take part. From this list, a random sample of children will be compiled to take part in the research. Due to time constraints it is not possible for a large number of children to make up the sample. If your child is selected from the list, we will ask their class teacher for some basic personal information about them such as their age, gender and current levels of attainment in class.

If you do not wish for this information to be shared, then please do not complete this consent form.

What will participation involve?

The research will take place in the classroom at N***** C. of E. Primary School. It will be at a time arranged by the researcher and class teacher for when it would be most appropriate during your child's school day, and the actual experiment will take no longer than forty minutes in total. In order to test attention patterns in the classroom, if your child is selected to participate they will be asked to complete a test measuring an important skill known as working memory, which should take no longer than fifteen minutes in total. Then at a later stage they will be required to wear a pair of Tobii glasses. These are basically like a pair of glasses with the ability to record eye movements, whilst having no effect on what the wearer can actually see. They are designed to comfortably fit the face, and will only be worn by the child for around fifteen minutes of the experiment, during class time.

The nature of the device used to measure attention patterns means that it is possible that other children will be captured in the video technology, but this information will be destroyed once it has been analysed. Furthermore, no information with respect to other children will be used or stored as part of the study. Full information Governance rules will be followed including all video information being locked in an encrypted computer in a locked facility, with highly restricted access.

The attention patterns of the children directly involved in the study will be later coded for analysis, and each child will be given their own identity code that the researcher will refer to in their analysis so none of the children will be identifiable. The findings from the data may be used for publication, i.e. for research reports and presentations. Importantly, neither the children's names nor the school name will be directly referred to, in order to maintain their anonymity. If, up to three months after data collection, you wish to withdraw your child's data please don't hesitate to contact me with the details below and it will be removed from the analysis. In addition, your child is free to withdraw from the study at any time should they not want to take part.

If you wish to consent for your child to take part, please keep this information sheet as it has the researcher's details on if you were to have any questions. Furthermore, please also sign and return the consent slip presented underneath to your child's class teacher.

Additionally, if you have any concerns about the research you may also contact Dr Emma Marsden, chair of the Education Ethics Committee, emma.marsden@york.ac.uk.

Yours Sincerely,

Emma Campbell (erc519@york.ac.uk)

Department of Education,

York University,

York, YO105DD

Consent Form

I have read and understood the information given to me about the study and give my permission for my child, ……………………………………………………………………………(Name) to take part in the research:

“Attention patterns of primary school aged children in a classroom setting”

1. I am aware of the aims and procedures involved in this research and the opportunity for me to enquire further.
2. I understand that participation is voluntary and that I am free to withdraw my consent at any point without giving any reason and without any negative consequences. Additionally, it is important to emphasise that the child will know that they are free to withdraw from the research at any point.
3. I agree that demographic information, such as current attainment levels, can be shared about my son/daughter.
4. I understand that my son/daughter may be recorded on video as a result of the experiment taking place in the classroom, and these recordings will be used for analysis purposes only.
5. I understand that all information obtained from my son/daughter will be kept confidential.

Signed...Parent/Guardian

Please print your name..

Date…………………………..

Appendix C

Where do you like to look?

Hello, here is an information sheet for you! My name is Emma, and I am trying to test where schoolchildren like to look when they are in their classroom. Please have a look at this leaflet and call me if you have any questions. Thank you for reading this.

What is the study about?

I am interested in where young people tend to look when they are hard at work in the classroom.

Why have I been chosen?

I am asking all of the children in your class if they would like to take part, and with your help we can learn more about your experience in school on a daily basis!

What will happen?

You will be asked to complete a couple of quizzes then to wear some glasses designed to record where you are looking for a short time during one of your lessons.

(The glasses don’t affect how and what you see!)

What happens next?

Of course, if you let me know before the experiment takes place or even during the experiment if you need to. And you don't have to tell me why. If you do choose to take part, but change your mind afterwards you can let me know up to 3 months after the study and your clip will not be studied.

Please feel free to contact me about this leaflet:

Emma Campbell

Email: erc519@york.ac.uk

Appendix D

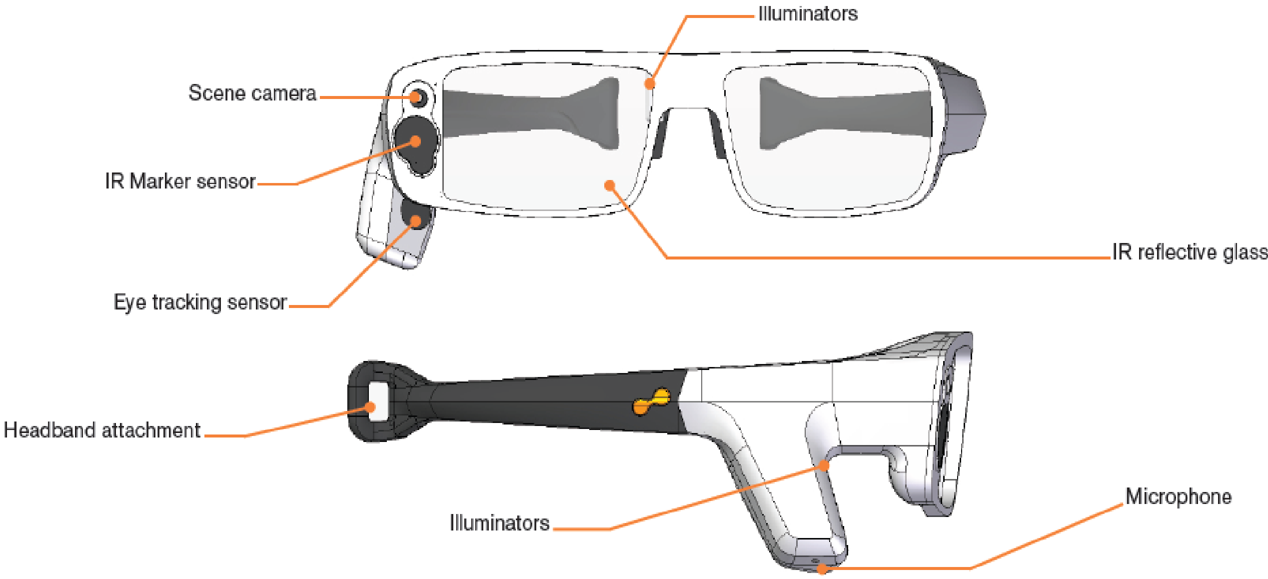

Figure D1: A diagram depicting the composition of the Tobi 1 Glasses used in this research (obtained from: http://www.tobii.com/Global/Analysis/Downloads/Product_Descriptions/Tobii_Glasses_Product_Description.pdf)

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