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Fine motor skill proficiency in typically developing children: On or off the maturation track?

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ABSTRACT

Fine motor skill proficiency is an essential component of numerous daily living activities such as dressing, feeding or playing. Poor fine motor skills can lead to difficulties in academic achievement, increased anxiety and poor self-esteem. Recent findings have shown that children's gross motor skill proficiency tends to fall below established developmental norms. A question remains: do fine motor skill proficiency levels also fall below developmental norms? The aim of this study was to examine the current level of fine motor skill in Irish children. Children ($N = 253$) from 2nd, 4th and 6th grades (mean age = 7.12, 9.11 and 11.02 respectively) completed the Fine Motor Composite of the Bruininks Oseretsky Test of Motor Proficiency 2nd Edition (BOT-2). Analysis revealed that only 2nd grade children met the expected level of fine motor skill proficiency. It was also found that despite children's raw scores improving with age, children's fine motor skill proficiency was not progressing at the expected rate given by normative data. This leads us to question the role and impact of modern society on fine motor skills development over the past number of decades.

1. Introduction

Fine motor skills are the use of small muscles involved in movements that require the functioning of the extremities to manipulate objects (Gallahue & Ozmun, 2006). Fine motor skills play a key role in many activities of daily living such as self-care, feeding and dressing (Marr, Cermak, Cohn, & Henderson, 2003; Van der Linde et al., 2013). A study by McHale and Cermak (1992) found that children spend between 30% and 60% of their school day performing fine motor tasks. Those activities involving manipulation of writing implements, such as pencils, are perhaps the most important skill regarding academic achievement, with paper and pencil based activities making up as much as 85% of the time spent engaged in fine motor tasks (Marr et al., 2003). Children with strong fine motor skills have been found to demonstrate higher academic achievement, mathematical achievement and earlier development of reading (Cameron et al., 2012; Luo, Jose, Huntsinger, & Pigott, 2007). Overall, fine motor skill acquisition plays an important role in children's development as they enable participation in valued occupations of daily living, play, education and social interaction (Cools, Martelaer, Samaey, & Andries, 2009; Summers, Larkin, & Dewey, 2008a). However at present, little is known about the impact of changes occurring in the modern environment (i.e., technological and technical innovations) influence the development of fine motor skill in children.

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The dynamical systems theory offers a framework to help explain the interaction between all factors involved in these changes by postulating that the development of fine motor skill relies on the ever-changing relationship between all components of a system (e.g. the individual, the task and the environment – Newell, 1986). According to this model, motor development can be seen as the "continuous change in motor behavior throughout the life cycle, brought about by the interaction between the requirements of the movement task, the biology of the individual and the conditions of the environment" (Gallahue & Ozmun 2006, p.25). According to Thelen and Smith (1994), development is contingent and constantly evolving based on the environment in which it takes place. Children now grow up in an environment where they are exposed to more time engaging with digital devices such as television, tablets and video game consoles (Biddle, Pearson, Ross, & Braithwaite, 2010; Lauricella, Wartella, & Rideout, 2015). These changes seem to be progressing at an alarming rate with young people consuming an average of seven hours and thirty-eight minutes of media daily, an increase of one hour and seventeen minutes since the previous measure five years previously (Rideout, Foehr, & Roberts, 2010; Roberts & Foehr, 2005). As such, the environment in which children now grow up in can be quite passive with increased opportunity for engagement in sedentary behaviors that limit the varied movement experiences required for typical motor development (Maitland, Stratton, Foster, Braham, & Rosenberg, 2013).

Thelen and Smith (1994) argue that development is a function of the interaction between genetically determined processes and input from the environment. As motor development is a result of the interaction between the task, the individual and the environment, changes in any of these constraints have consequences on the acquisition of motor skills (Newell, 1986). There is evidence that demonstrates how these environmental changes have negatively influenced the levels of gross motor skill development and, in particular, FMS proficiency (Hardy, Barnett, Espinel, & Okely, 2013). A study by O'Brien, Belton, and Issartel (2015) found that only 11% of Irish 11–14 year-olds reached mastery level of 9 FMS tested. This is particularly alarming considering all skills should be mastered by ten years of age (Gallahue & Ozmun, 2006). As gross motor skill proficiency has decreased in recent times as a result of environmental factors, it is, therefore, plausible to assume that fine motor skills have also been affected. A question remains, do these environmental changes positively or negatively affect the fine motor skill development of children? As many screen-based activities such as playing video games or using tablets require fine motor skills, one could expect that these changes could potentially increase children fine motor skill proficiency levels. This has been suggested in the laparoscopic training of surgeons (Adams, Margaron, & Kaplan, 2012; Badurdeen et al., 2010; Rosser et al., 2007). On the other hand, certain fine motor skills could be at risk of being 'lost in the sea of instant messaging and other technologies' causing children's fine motor skill acquisition to pursue a different trajectory and fall below the expected levels for children's age and gender in the past (Coll, 2015).

When considering the motor skill level of children, it is crucial to take into account the full range of motor skill proficiency. On the lower end of the spectrum, children with motor skill impairments such as those with Developmental Coordination Disorder (DCD) are frequently reported as having difficulty when tying shoelaces, buttoning shirts, doing up zippers, brushing their teeth and using cutlery (Cairney, Hay, & Flouris, 2005; Magalhães, Cardoso, & Missiuna, 2011; Missiuna, 1994; Summers, Larkin, & Dewey, 2008b; Wang, Tseng, Wilson, & Hu, 2009). These children frequently suffer from a range of physical, social and emotional consequences (Fitzpatrick & Watkinson, 2003; Henderson & Henderson, 2003). In general, children with motor skill impairments are often subject to ridicule and embarrassment, reduced self-efficacy and lower self-esteem as a result of their motor coordination problems (Cairney et al., 2005; Fitzpatrick & Watkinson, 2003; Mandich, Polatajko, & Rodger, 2003). Some studies have shown that this leads to avoidance of participation in activities that highlight their impairments such as play and social interaction (Bart, Jarus, Erez, & Rosenberg, 2011; Fitzpatrick & Watkinson, 2003; Fong et al., 2011). Unfortunately, these motor coordination problems frequently persist into adolescence and adulthood (Cousins & Smyth, 2003; Geuze & Börger, 1993; Losse et al., 1991). This is contrary to the belief that fine motor skill difficulties are just a stage that children "grow out of" (Losse et al., 1991). However, not all children with fine motor skill difficulties have DCD. This raises the following question: what happens to children who experience mild fine motor skill problems that cause them to fall behind the expected rate of development? With time, do these children manage to catch up and reach a mature level of fine motor skill proficiency? On the contrary, these difficulties may persist throughout life and ultimately affect their quality of life. In both cases, it is important to find out if and how the current generation of children's fine motor skill proficiency has been affected and whether the fine motor skills necessary to succeed in modern society have been influenced by environmental factors.

In the present study, we aimed to examine the current level of fine motor skill proficiency in typically developing (TD) children and assess whether children are developing their fine motor skills at the expected rate, or whether their development has been affected by recent changes in the environment. Due to the complex level of interaction between environmental factors, it was anticipated that these changes have led to some components of fine motor skill to improve and other components to deteriorate.

2. Methods

2.1. Participants

A total of 253 children (139 males and 114 females aged 6–12 years) took part in this study. The children (71% Irish Caucasian) were randomly selected from 5 different primary schools in the Dublin area (Ireland) between January 2013 and May

2014. Children's socioeconomic status (SES) was determined by using postcode as a proxy measure accordingly to census data. The children who participated were predominantly of lower to middle social class.

The children were divided into 3 age groups, 2nd grade (51M 39F, $M_{age} = 7.12$), 4th grade (47M 33F, $M_{age} = 9.11$) and 6th grade (41M 42F, $M_{age} = 11.02$) based on their year of study in primary education. Ethical approval was received from the University Research Ethics Committee. Prior to the study, the parents/guardians of each child provided informed consent for their child to participate. Three children with intellectual (Autistic spectrum disorder) or physical disabilities (Wheelchair user with Muscular Dystrophy) were excluded from the analysis, as they could not complete the testing protocol.

2.2. Procedures

Children's fine motor skill proficiency was assessed using the Fine Motor Composite of the BOT-2 (Bruininks & Bruininks, 2005). The fine motor composite is made up of two composite areas: fine manual control and manual coordination. Fine manual control composite is divided into two subtests, fine motor precision (FMP) (7 items, score range = 0–41) and fine motor integration (FMI) (8 items, score range = 0–40) including activities such as writing, cutting and folding which require precise control of finger and hand movements. The manual coordination composite, which measures children's throwing, catching, and object manipulation, with an emphasis on speed and dexterity, is split into manual dexterity (MD) (5 items, score range = 0–45 points) and upper-limb coordination (ULC) (7 items, score range = 0–39 points). The point scores are summed to give total point scores, which in turn are converted to scale scores ($M = 15$; SD = 5) for each subtest. The scores for the total fine motor composite are reported as total scale scores; standard scores ($M = 50$; SD = 10); or percentile ranks that are age and gender adjusted. In addition, findings can be reported as Descriptive Categories ranging from "Well-Below-Average" to "Well-Above-Average."

2.3. Statistical analysis

Data was analyzed using IBM SPSS 21for Mac OS. Descriptive statistic's were calculated for anthropometric and motor skill variables. One sample *t*-tests were carried out on the Total Fine Motor Composite score for each grade to compare against the expected norms. Point Scores for each subtest were used to analyze the effect of grade and gender using two-way between groups ANOVA's. A repeated measure's ANOVA was carried out on the standard scores for FMC and MC composites to investigate the effect of age and gender when necessary. Post-Hoc tests using the Bonferroni correction were carried out on significant effects.

3. Results

According to the descriptive scoring categories for standard scores provided by the BOT-2, 36% of the 6th grade cohort fell into the below average category compared to 13% and 12.5% for the 2nd and 4th grade respectively (see Table 1). A series of one sample *t*-test's were carried out on Total Fine Motor Composite Scores to compare each grade to the normative score of 50. There was a significant difference in scores for 6th grade ($M = 44.55$, SD = 7.90; $t(82) = 6.28$, $p < .01$ and 4th grade ($M = 47.50$, SD = 7.02; $t(79) = 3.187$, $p < .01$) compared to the population norm.

A two-way between groups (Gender $\times$ Grade) ANOVA was carried out on the standard score for the Fine Motor Composite Score to assess the effect of gender and grade. There was no interaction effect found between grade and gender $F(2,247) = 1.30$ $p < .05$. There was a main effect found for grade, $F(2,247) = 10.03$ $p < .01$, $\eta_\rho^2 = .08$. Post Hoc test using the Bonferroni correction revealed that mean score for 2nd grade children ($M = 50.02$, SD = 8.46) differed significantly from that of 6th grade children ($M = 44.55$, SD = 7.90). There was no significant main effect found for Gender $F(1,247) = 1.64$, $p > .05$.

A 2 (Composite) $\times$ 2 (Gender) $\times$ 3 (Grade) repeated measures ANOVA was carried out the standard scores for FMC and MC composites. There was a significant interaction effect between grade and composite, Wilks' Lambda = 0.95, $F(2,247) = 5.93$, $p < .01$, $\eta_\rho^2 = .05$. Post Hoc tests using the Bonferroni correction revealed that 6th grade children ($M = 44.80$, SD = 7.57) scored significantly lower than 4th grade ($M = 49.35$, SD = 7.48) and 2nd grade ($M = 51.74$, SD = 7.64) peers for the FMC composite but there were no significant differences between grades in MC scores with 2nd, 4th and 6th grade children scoring 47.63, 46.70 and 45.43 points respectively.

A 4 (Subtest) $\times$ 2 (Gender) $\times$ 3 (Grade) repeated measures ANOVA was carried out the point scores for each of the 4 subtests. A main effect was found for grade, $F(2,250) = 43.44$, $p < .01$ on the point scores for FMP subtest, with a large effect size,

Table 1
Percentage of each age group that fall into BOT-2 Descriptive Categories.

Grade	Well above average (%)	Above average (%)	Average (%)	Below average (%)	Well below average (%)
2nd grade	0	6.66	80	13.33	0
4th grade	0	1.25	85	12.5	1.25
6th grade	0	5	59	36	0
Overall	0	8	69	22	0.8

$\eta_\rho^2 = .26$. Post hoc tests using the Bonferroni correction found that 2nd grade children (*M* = 29.19, SD = 5.54) scored significantly ($p < .01$) lower compared to their 4th (*M* = 33.65, SD = 4.29) and 6th (*M* = 35.63, SD = 3.92) grade peers in addition to a significant difference being found between 4th and 6th grade ($p < .05$). There was also significant main effect for grade for the FMI subtest, $F(2,250) = 16.42$, $p < .01$, $\eta_\rho^2 = 0.12$. Post hoc tests using the Bonferroni correction showed that 2nd grade (*M* = 33.97, SD = 4.40) scored significantly lower compared to 4th (*M* = 36.23, SD = 3.48) and 6th (*M* = 36.92, SD = 2.41) grade children ($p < .01$). Significant main effects were also for grade on the point scores for the MD ($F(2,250) = 113.82$, $p < .01$) and ULC ($F(2,250) = 91.60$, $p < .01$) subtests both with large effect sizes ($\eta_\rho^2 = .48$ and $\eta_\rho^2 = .42$ respectively). Post Hoc tests with Bonferroni correction found that all 3 grades groups performance differed significantly on MD scores ($p < .01$) with 2nd grade (*M* = 21.11, SD = 3.79) once more scoring lower than their 4th (*M* = 25.45, SD = 3.86) and 6th (*M* = 30.11, SD = 4.11) grade peers. Post hoc tests found that all grade groups differed significantly ($p < .01$) for ULC with 6th grade (*M* = 34.17, SD = 2.90) scoring higher than their 4th (*M* = 31.08, SD 5.72) and 1st (*M* = 22.09, SD 8.27) grade peers. Main effects for gender were found for FMP and ULC subtests ($p < .01$). Males were found to score significantly lower (*M* = 31.99, SD = 5.86) for FMP and significantly higher for ULC (*M* = 29.56, SD = 8.21) than females (*M* = 33.92, SD = 4.5 and *M* = 28.08, SD = 7.74 respectively).

4. Discussion

This study investigated the current level of fine motor skill proficiency of children aged 6–12 years. Overall, the main findings highlight that children's subtest point scores (performance before gender and age correction) do improve with age (Fig. 2). These age-related differences mirrors those found by D'Hondt et al., 2011 in a study examining gross motor skill proficiency. Similarly, Bardid, Rudd, Lenoir, Polman, & Anderson, 2015 found that older children perform better than their younger peers on gross motor coordination activities. However, our results revealed that children fall below the expected levels (standard score of 50) given by normative data (Fig. 1). These results seem to be in contradiction with the typical theory of development, with the youngest children appearing to demonstrate the best scores. These differences demonstrate that children's fine motor skill proficiency does not regress with age, rather that children's fine motor development does not occur at the expected rate. This finding emphasizes the downward trend observed in the literature on children's motor skill proficiency falling below expected levels (Bardid et al., 2015; Hardy et al., 2013; Okely, Booth, & Chey, 2004). As a result of the standardized nature of motor skill assessments, the task constraint can be seen as remaining constant, and as any biological changes in children in the past decade are likely to have had negligible effect on motor skill proficiency. Therefore, it is reasonable to assume that any differences found are likely the result of changes in the environmental constraint. One of the

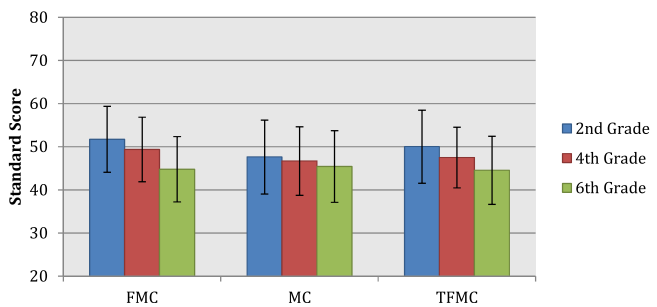

Fig. 1. Standard scores for fine manual control (FMC) and manual coordination (MC) units and Total Fine Motor Composite (TFMC).

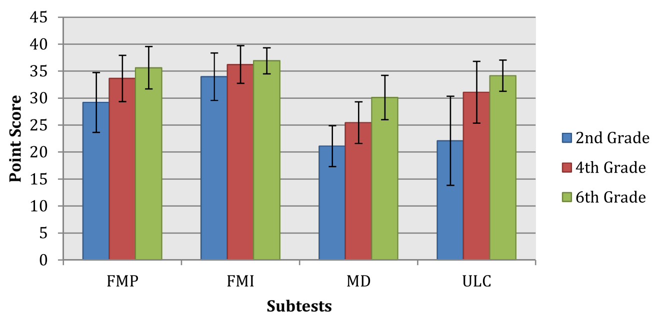

Fig. 2. Point scores for fine motor precision (FMP), fine motor integration (FMI), manual dexterity (MD) and upper-limb coordination (ULC) subtests.

potential reasons that could explain changes in the well-established norms of motor development is the increasingly prominent role that technology plays in modern society. A number of studies have shown how children now grow up in media-saturated environments with technology playing a central role in their daily life (Lauricella et al., 2015; Rideout et al., 2010; Vandewater et al., 2007). These relatively new leisure time activities have taken the place of traditional activities such as playing with blocks, Lego©, board games or jigsaws with a potentially detrimental effect on the rate of development of fine motor skills. To better understand and link all these elements together, it seems important to refer to Thelen and Smith (1994) who suggested that there is an intimate relationship between an individual and the physical and informational properties of the environment around them. As motor skill development emerges from this dynamic relationship between the organismic and environmental components, any changes in these properties influence motor skill acquisition. In this instance, the lack of practice of the skills that compose the various activities of each subtest such as catching, throwing or manipulation of objects such as pencils, scissors, cards or block. The FMP and FMI subtests are mainly composed of activities that rely on the grip and manipulation of a pencil. The development of pencil grip used for writing is a complex skill which has been found to improve with age as a result of practice (Schwellnus et al., 2012). Surprisingly, only 2nd grade children were found to reach the expected level for the FMC composite, which includes both FMP and FMI subtests. In the past, pencil and paper activities were found to be a core component of school tasks making up 85% of the timing carrying out fine motor skills (Marr et al., 2003). However, changes in the teaching methodologies used in school and leisure time activities that children now engage in may have reduced the time spent engaging in drawing activities in favor of more technology based activities (Flewitt, Messer, & Kucirkova, 2014). Additionally, the MD subtest showed the lowest scores of all the subtests. This subtest is also composed of activities involving the manipulation of objects with an added component: a time-pressured environment (e.g. placing as many pegs in a board as possible in 15 seconds). It is likely that any difficulties that children have in control and manipulation of objects would be magnified by tests where the level of success is constraint by time in comparison with the FMP and FMI subtests that are completed without a time constraint. The ULC subtest relies heavily on hand–eye coordination of a child. Traditionally, most children would participate in throwing and catching activities from a young age that would help develop hand–eye coordination. Therefore, it is not surprising to see children falling below expected proficiency levels for the ULC subtest, given the reduction in physical activity and motor skill competence in recent years (Bardid et al., 2015; Hardy et al., 2013; Okely et al., 2004; Woods, Moyna, Quinlan, Tannehill, & Walsh, 2010). The finding that standard scores for the MC composite do not differ significantly between grades suggests that component of fine motor skill is progressing steadily for all ages while still falling below normative levels.

Previous research has shown that cultural differences influence the motor skill proficiency of children (Bardid et al., 2015; Chow, Henderson, & Barnett, 2001; Chui, Ng, Fong, Lin, & Ng, 2007; Lam, 2008; Lam & Schiller, 2001; Luo et al., 2007; Saraiva, Rodrigues, Cordovil, & Barreiros, 2013). Studies by Chow et al. (2001) and Chui et al. (2007) both found differences in components of fine motor skill between children from Hong Kong and their American counterparts. Children from Hong Kong were found to score higher for manual dexterity units while American children scored better for upper limb coordination subtests that require projection and interception of objects (Chow et al., 2001; Chui et al., 2007). Bardid et al., 2015 have also found cultural differences between Belgium and Australian children on some of the subtests of the Körperkoordinationstest für Kinder (KTK). These findings emphasis the need for caution when using norms developed in one country as a direct comparison to the performance by children of another country (Lam, 2008). Additionally over the last decade, lifestyles across the world have changed significantly due to advances in technology and increased standards of living, which has altered children's leisure time activities and physical activity patterns (Bardid et al., 2015; Dollman, 2005). Consequently, one can question whether the current level of children's motor competence would reach the level previously observed in the past.[1] It is reasonable to assume that lack of motor skill proficiency observed in this article and the studies mentioned above can be attributed to a combination of both cultural and societal changes.

In this study, males were found to score higher than females for throwing and catching activities in the point scores ULC subtest whereas females scored significantly higher for drawing and cutting activities of the FMP subtest. Research has shown that gender differences are likely as a result of environmental influences such as lack of opportunities to practice, encouragement and reinforcements that female motor proficiency is lower rather than genetic differences (Haywood & Getchell, 2009; Hume et al., 2008; Okely & Booth, 2004). The ULC subtest contains object control skills such as throwing, catching and bouncing, which boys have been found to be more proficient in compared to girls (Barnett, van Beurden, Morgan, Brooks, & Beard, 2009; Blakemore, Berenbaum, & Liben, 2009). The manual dexterity subtest not only contains some object control skills (sorting cards and moving pegs) but also is measured in a time-pressured environment. Subjectively, boys tended to demonstrate greater motivation to improve score between trials during test compared to girls. This is in keeping with research which shows boys to display more competitive and egocentric nature compared to girls more cooperative and calmer demeanor (Garcia, 1994). The FMP subtest involves less competitive fine motor skill tasks (no time pressure) and encourage precision and accuracy such as; tracing lines and drawing shapes, which often have a female gender bias associated with them (Garcia, 1994; Hardy, King, Farrell, Macniven, & Howlett, 2010). However, as gender differences are frequently observed in motor skill proficiency in children (Barnett, van Beurden, Morgan, Brooks, & Beard, 2010; Breslin, Murphy, McKee, Delaney, & Dempster, 2012), the BOT-2 provides gender adjusted norms which control for gender bias. As a result, these gender differences were not present when analyzing the standard scores. These low level's of motor skill

[1] *Note:* KTK was validated in 1974 and the BOT-2 was last validated in 2005.

proficiency can have multiple repercussions for teachers, parents, and children themselves. Children with fine motor skill impairments have problems with everyday activities such as using utensils to eat or dressing themselves (Zwicker, Missiuna, Harris, & Boyd, 2012) in addition to decreased levels of social interaction with peers (Mandich et al., 2003). In relation to academic achievement, children with fine motor skill difficulties frequently take longer to complete tasks as a consequence of problems with the manipulation of the pencil. They tend to be exposed to fewer learning experiences, with less practice time to develop their skills in the classroom in comparison with their peers (Cameron et al., 2012). Consequently, these children's fine motor skill proficiency will fall behind their more skilled peers. The finding that children's motor skill is not progressing at the expected rate could lead to the creation of a new sub-group with a lower the level than TD children while being above the level of children with impairments that are of clinical implications (e.g. DCD).

However, it is also important to mention that there is some evidence that video gaming can lead to improvement in manual dexterity and hand–eye coordination in laparoscopic surgery training in surgeons (Adams et al., 2012; Badurdeen et al., 2010; Rosser et al., 2007). Touch screen devices require several actions such as swiping, dragging and dropping, pushing or tapping which all require fine motor skill to perform (Price, Jewitt, & Crescenzi, 2015). As such, it might be possible that children are now developing a new set of fine motor skills that meet the demands of the environment that they are now faced with. These new skills allow for the proficient use of touch screen technologies or games consoles.

5. Conclusions

As these "new fine motor skills" are not measured by traditional tests of like the BOT-2, this may require the adjustment of the tasks currently used to assess fine motor skill or the creation of additional tests to accurately measure fine motor skill proficiency while ensuring the influence of the current environment is taken into account. It is unlikely that there is a unique root cause of these motor development delays. According to the dynamical systems approach, these differences are likely the result of an accumulation of many small changes in the environment leading to significant differences between children's current level of fine motor develop proficiency and what has been considered typical development in the past (Thelen & Smith, 1994). However, further longitudinal studies are required to ascertain whether children eventually catch up with their expected rate of development or whether these differences continue to exist into adulthood. In addition, there is a need to assess how engagement in physical activity, sedentary behavior, and screen time activities could influence children's fine motor skill proficiency levels.

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