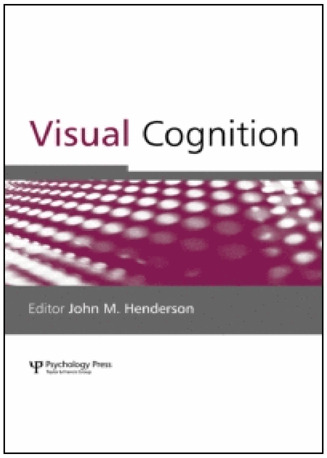

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The composite face effect in six-year-old children: Evidence of adult-like holistic face processing

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Holistic processing (i.e., gluing facial features together into a gestalt) is a hallmark of adults' expert face recognition. Children make more errors than adults on a variety of face processing tasks even during adolescence. To determine whether this slow development can be attributed to immature holistic processing of unfamiliar faces, we tested 6-year-old children ($n = 24$) with a classic measure of adults' holistic processing, the composite face effect: They made same/different judgements about the top halves of face pairs when each top half was combined with a different bottom half, with which it was aligned (so that holistic processing creates the impression of a different face) or misaligned (a manipulation that disrupts holistic processing). Six-year-olds showed an adult-like *composite face effect*: Like adults, they made 26% more errors on aligned trials than on misaligned trials. These results suggest that the improvements after age 6 in the recognition of the facial identity are not caused by the onset or increasing strength of holistic face processing.

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Unlike other objects, faces elicit holistic processing (Tanaka & Farah, 1993): Their parts are integrated into a gestalt that allows adults to see the face as a whole, thereby reducing the accessibility of information about individual features (for a review, see Maurer, Le Grand, & Mondloch, 2002). A compelling demonstration of holistic processing is the *composite face effect* (Carey & Diamond, 1994; Hole, 1994; Hole, George, & Dunsmore, 1999; Le Grand, Mondloch, Maurer, & Brent, 2004; Michel, Rossion, Han, Chung, & Caldara, in press; Young, Hellawell, & Hay, 1987). Adults find it difficult to recognize the top half of a celebrity's face when it has been aligned with the bottom half of a different face (Young et al., 1987). Presumably holistic processing binds the two halves of the face and creates a novel face, thereby making it difficult to recognize the person in the top half even when instructed to ignore the bottom half. Adults perform better after manipulations that disrupt holistic processing such as misaligning the two halves or inverting the face (Young et al., 1987). The composite face effect also occurs for same/different judgements about the top halves of unfamiliar faces (Hole, 1994; see Figure 1). In addition, adults recognize the features from an individual's face more easily in the context of the whole face (e.g., Larry's nose in Larry's face) than in isolation (*the whole/part advantage*) (Tanaka & Farah, 1993). These findings demonstrate that facial features are not only represented individually, but are also integrated into a holistic representation that interferes with access to the representation of any individual feature.

Figure 1. Composite face stimuli. Two face pairs from the misaligned condition are in the top row, and two face pairs from the aligned condition are in the bottom row. In each face pair, the top halves are either identical (examples in left panel) or different (examples in right panel). For all face pairs, the bottom halves are different. In the aligned condition, holistic processing creates the impression that the top halves are always different. Reprinted with kind permission from Le Grand, R., Mondloch, C. J., Maurer, D., & Brent, H. P. (2004). Impairment in holistic face processing following early visual deprivation. *Psychological Science*, *15*, 762–768. Oxford: Wiley-Blackwell Publishing Ltd.

Although a rudimentary form of holistic processing is evident by 4 months of age (Cashon & Cohen, 2003; 2004), holistic processing appears to be tuned by postnatal experience with human faces. Neither the composite face effect nor the whole/part advantage occurs for inverted faces. The whole/part advantage does not occur for drawings of houses (Tanaka & Farah, 1993) and the composite face effect does not occur for unfamiliar objects like greebles with which the viewer has not been trained (Gauthier & Tarr, 2002). Both effects are stronger for own-race than other-race faces, unless the subject has been living for more than a year among individuals of the other race (Michel, Caldara, & Rossion, 2006; Michel, Rossion, et al., in press; Tanaka, Kiefer, & Bukach, 2004). Thus, like expert face recognition (Mondloch, Maurer, & Ahola, in press; Pascalis, Demont, de Haan, & Campbell, 2001; Rhodes, Wayward, & Winkler, in press; Sangrigoli, Pallier, Argenti, Ventureyra, & de Schonen, 2005) holistic processing is stronger for categories of faces with which the observer has had a wealth of experience.

The role of experience is also evident in studies of patients who were deprived of early visual experience by congenital cataracts. Visual deprivation during the first few weeks or months of life prevents the later development of normal holistic processing as measured by the composite face task. When tested for the composite face effect at a mean age of 15 years (range 9–23 years), patients showed no evidence of holistic processing and in fact performed better than controls on the critical condition where holistic processing interferes with accuracy: Patients were more accurate and faster than controls in seeing that two top halves were the same when the top halves were aligned with two different bottom halves and, unlike controls, did no better when the halves were misaligned to break holistic processing (Le Grand et al., 2004). By this superior performance, the patients demonstrated that they do not process faces in a normal holistic manner. Thus, early visual experience is necessary to set up (or maintain) the neural architecture that allows the development of normal holistic processing.

Children do not reach adult levels of expertise in recognizing facial identity until adolescence (Carey, Diamond, & Woods, 1980; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch, Le Grand, & Maurer, 2002), even in matching tasks that eliminate memory demands (Bruce et al., 2000). In the present study we investigated whether immature holistic processing contributes to the slow development of adult expertise in recognizing unfamiliar faces.

Previous studies have shown that children as young as 4 years show the whole/part advantage with no significant change in the size of the effect between 6 and 10 years of age (Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998) or between age 4 and adulthood (Pellicano & Rhodes, 2003): At every age tested, subjects were more accurate at picking out a previously seen face from one in which a feature had been altered than they were in discriminating between the isolated parts. However, the whole/part effect may measure holistic processing in a different way from the composite effect. Unlike the composite face effect, Gauthier and Tarr (1997) found that the whole/part effect occurs even for objects with which the observer has not developed any expertise. In some respects, it is an example of the long-standing finding that objects are recognized more readily in the context in which they were first learned, i.e., Bob's nose is easier to recognize when seen in the original context of Bob's face. Admittedly, the whole/part effect is stronger for upright than inverted faces and does not occur for drawings of houses (Tanaka & Farah, 1993), but nevertheless it is unclear whether it measures exactly the same aspects of processing as the composite face effect.

Only one study has assessed children's holistic processing by using the composite face effect (Carey & Diamond, 1994). When asked to identify the top half of composite faces, 6- and 10-year-old children, like adults, were faster on misaligned trials than on aligned trials. However, in this study the faces were familiar either because they were the faces of classmates (Experiment 1) or because the children had been familiarized with the faces in the laboratory prior to testing (Experiment 2). In the current study, we examined whether 6-year-olds also show evidence of adult-like holistic processing of unfamiliar faces. Unlike adults, children might begin to show holistic processing for a face only after learning to recognize its features readily, a process similar to the switch from feature-by-feature to global recognition seen in adults learning to identify novel objects (Gauthier & Tarr, 2002). In addition, there is evidence that familiar and unfamiliar faces are processed differently by adults (Young, Hay, McWeeny, Flude, & Ellis, 1985). Both the composite face effect and the whole/part effect are weaker for categories of faces with which an adult is less familiar, namely other-race faces (Michel, Caldara, & Rossion, 2006; Michel, Rossion, et al., in press; Tanaka et al., 2004). However, using the *peripheral inversion effect* as a measure of holistic processing (McKone, 2004), McKone and colleagues found that adults do show evidence of holistic processing for the faces of specific individuals from another race with whom they are familiar (McKone, Brewer, MacPherson, Rhodes, & Hayward, in press). Thus, adults process familiar but not unfamiliar other-race faces holistically. In this study we investigated whether 6-year-olds, who are known to process familiar faces holistically, also do so with unfamiliar faces.

A smaller composite face effect for unfamiliar faces in children than seen in adults would suggest that changes in holistic processing contribute to the development of adult expertise in recognizing facial identity. An adult-like composite face effect for unfamiliar faces in young children would suggest that holistic processing matures during early childhood and that it may be necessary but not sufficient for adult-like expertise in facial recognition.

A second purpose of the study was to investigate the relationship between the pattern of normal development and the effect of early visual deprivation from bilateral congenital cataracts. A traditional hypothesis is that visual abilities that develop more slowly are more vulnerable to abnormal visual experience. This is known as the Detroit Principle: Last hired, first fired (Levi, 2005). Our previous studies of children treated for unilateral or bilateral congenital cataract indicate that the Detroit Principle accurately predicts the pattern of deficits for low level vision: Deficits are greater for capabilities that develop later, especially when early visual deprivation was accompanied by unfair competition between a normal eye and an eye with a cataract. For example, sensitivity to high rates of flicker becomes adult-like during infancy but sensitivity to slow rates of flicker improves up to 7 years of age (Ellemberg, Lewis, Liu, & Maurer, 1999); children with a history of early visual deprivation from cataract have normal sensitivity to high but not slow rates of flicker (Ellemberg, Lewis, Maurer, Liu, & Brent, 1999). Thus, early experience can set up or preserve the neural substrate for a capability that will emerge at a much later point in development. When the early experience is lacking, the capability fails to develop normally many years later, a pattern known as a *sleeper effect*.

Our previous studies of face processing indicate a match between relative rate of development and adverse effects of visual deprivation. For example, recognition of facial identity based on the shape of internal features or the external contour is (nearly) adult-like by 6 years of age (Mondloch et al., 2002) and is spared after early visual deprivation (Le Grand, Mondloch, Maurer, & Brent, 2001; 2003), whereas recognition based on the spacing of facial features develops much more slowly, with even 14-year-olds making more errors than adults (Mondloch, Le Grand, & Maurer, 2003), and it is seriously impaired after early visual deprivation (Le Grand et al., 2001, 2003). Similarly, when tested on their ability to match faces on a variety of dimensions (direction of eye gaze, vowel being mouthed, emotional expression, facial identity despite changes in head orientation or changes in facial identity) patients treated for bilateral congenital cataract performed poorly on only the one aspect of face processing that was not adult-like by 10 years of age: Recognizing facial identity across changes in head orientation (Geldart, Mondloch, Maurer, de Schonen, & Brent, 2002; Mondloch, Geldart, et al., 2003). In previous work we found that early visual deprivation prevents the development of normal holistic processing as measured by the composite face task used in the current study (Le Grand et al., 2004). Testing visually normal 6-year-old children on the same composite face task allowed us to investigate the relationship between the rate of normal development and the effects of visual deprivation in a new domain. If the Detroit principle holds for face processing, then holistic processing of unfamiliar faces should be immature at 6 years of age, as are the other aspects of face processing impaired by early visual deprivation (recognition of identity based on spacing of features or despite a change in point of view).

METHOD

Participants

Twenty-four Caucasian 6-year-olds (± 3 months) participated in this study. Children were recruited from names on file of parents who had volunteered them at birth for participation in future studies. None of the participants had a history of eye problems, and all met our criteria on a visual screening exam: At least 20/20 acuity on the Goodlight Crowding test in each eye without optical correction, worse acuity with a $+3$ diopter lens (to rule out farsightedness greater than 3 diopters), fusion at near on the Worth Four dot test, and stereoacuity of at least 40 arc s on the Titmus test. All participants were right-handed, as determined by a handedness test adapted from Peters (1988). An additional nine participants were tested, but excluded from the final analysis because they failed visual screening ($n=2$), were not right-handed ($n=2$), were inattentive ($n=2$), failed the training task ($n=2$; see below), or failed the control task ($n=1$; see below).

Apparatus

The stimuli were presented on a monochrome Radius 21-GS monitor controlled by a Macintosh LC-475 computer and Cedrus Superlab software. The experimenter initiated trials by pressing a key on the keyboard and participants signalled their responses via a joystick.

Stimuli

Face composites were created from greyscale digitized images of adult Caucasian faces. Using Adobe Photoshop, we created composites by splitting face images in half horizontally across the middle of the nose, and then recombining the faces using the top and bottom halves of different individuals and eliminating the cut line by retouching in Photoshop. In the aligned condition, the top and bottom face segments were properly aligned. In the misaligned condition, the top half of each face was misaligned by shifting it horizontally to the left by half a face width (see Figure 1).

The same face composites were used in both conditions, and the location of the top half of each face was constant. Stimuli in the aligned condition were 9.8 cm wide and 14 cm high (5.6×8 visual degrees from 100 cm). Stimuli in the misaligned condition were 12.8 cm wide and 14 cm high (7.3×8 visual degrees from 100 cm).

Procedure

Children were tested in the same way as our previous study with adults and patients treated for bilateral congenital cataracts (Le Grand et al., 2004), with two exceptions: (1) Children were given training trials prior to the test trials, and (2) during test trials the second face remained on the screen until the child responded rather than disappearing after 200 ms. Pilot work indicated that testing the 6-year-olds with the adult procedure produced data like those reported here at the group level, but a number of children did not reproduce the group pattern of results.

Training trials. After a parent gave informed written consent, the child was seated in a dimly lit room 100 cm from the computer monitor. We began with a training task to ensure that all participants understood that their task was to make same/different judgements about only the top halves of each face pair. In the first training task, children were shown pairs of faces that consisted only of top halves. They were asked to make same/different judgements about each pair. The first stimulus remained on the screen for 1000 ms on the first four trials and for 200 ms for the remaining eight trials. Children were required to make a correct response on nine of the 12 trials to be included in the final sample; if necessary, each child was given two attempts to do so. Two children failed to reach this criterion. After reaching criterion, children were then given six additional training trials in which the bottom half of each face was misaligned with the top half. On the first two of these trials the first face was presented for 1000 ms; on the remaining four trials the first face was presented for 200 ms. Participants were asked to move a joystick forward if the top halves of the two faces were the same, and back if the top halves were different. They were asked to respond as quickly and accurately as possible. There was no criterion for inclusion based on this second training task.

Test trials. On each test trial, a composite face appeared for 200 ms, and following a 300 ms interstimulus interval, a second composite face appeared and remained on the screen until the child responded. Half of the children were tested on the misaligned ($n = 48$ trials), followed by the aligned ($n = 48$ trials) condition. They were given six practice trials prior to the aligned block. The remaining children were tested on the aligned, followed by the misaligned condition. They were given six practice trials prior to each block of trials. Within each block, half of the trials consisted of face pairs that shared the identical top halves (same trials), and half of the trials consisted of face pairs with different top halves (different trials). On every trial the bottom halves were different. Same and different trials were intermixed randomly within each block.

Control task. At the end of the procedure we tested children on a control task in order to ensure that they were still "playing the game". On each of 32 trials we presented pairs of faces sequentially and asked the child to indicate whether the two faces were the same or different; the faces were identical on half of the trials and were pictures of two different people on the other half. Participants were required to be correct on at least 70% of these trials in order to be included in the final sample. A single child was excluded for failing to meet this criterion.

RESULTS

Figure 2 shows the mean accuracy as a function of trial type for 6-year-olds and, for comparison, for adults tested with the same stimuli in a previous study (Le Grand et al., 2004). Alignment affected accuracy on both same and different trials. Like adults, children were much less accurate on same/aligned trials (mean percentage correct = 43%) than on same/misaligned trials (mean percentage correct = 69%). This difference in accuracy (mean = 26% and 23% for children and adults, respectively) is the composite face effect. Unlike adults, children showed the opposite pattern on different trials. They were more accurate on different trials when the two halves were aligned (mean correct = 82%) than when the two halves were misaligned (mean correct = 62%). The within-subjects ANOVA revealed significant main effects for correct response, same versus different, $F(1, 22) = 12.7$, $p < .01$, but no main effect of order ($p > .1$) or condition ($p > .1$). There was also a significant two-way interaction between condition and correct response, $F(1, 22) = 23.3$, $p < .001$, and between condition and order, $F(1, 22) = 4.8$, $p < .05$. All other interactions were not significant (all ps $> .1$). The analysis of simple effects revealed a significant effect of condition for same trials, $F(1, 23) = 26.3$, $p < .001$; effect size $\eta^2 p = 1.18$, and for different trials, $F(1, 23) = 15.9$, $p < .01$; effect size $\eta^2 p = 0.97$, with better accuracy for same misaligned trials and for different aligned trials. Although there was a significant interaction between condition and order, the pattern of results (i.e., better performance on misaligned trials when the correct response was same and better performance on intact trials when the correct response was

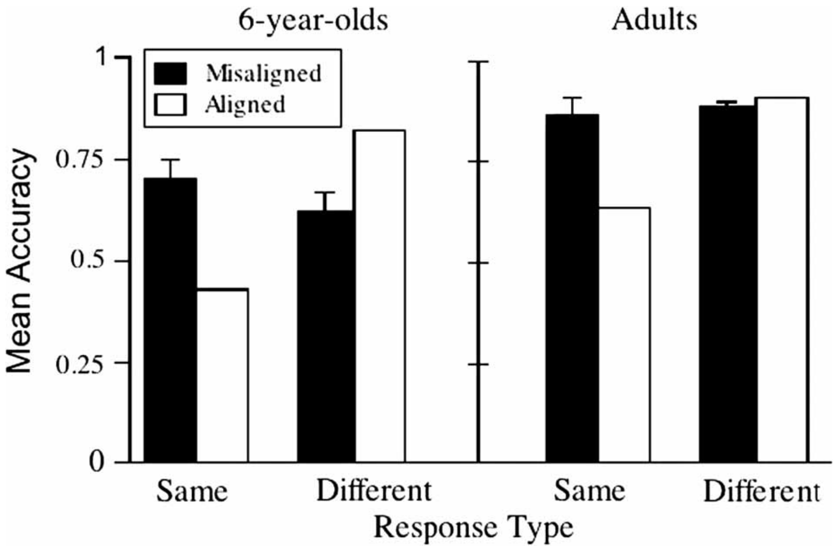

Figure 2. Mean proportion correct of 6-year-olds and adults on the composite face task. Because the study used a within-subjects design (and thus variance between age groups for each condition is irrelevant), the standard error bars represent intrasubject variability between conditions (see Loftus & Masson, 1994). The adult data were published previously in *Psychological Science*, 2004, *15*, p. 765; they are presented here for comparison.

different) was consistent across orders and analyses of simple effects revealed that accuracy did not differ across orders for either misaligned or intact trials (ps $>$.2).

An analysis of median reaction times confirmed that differences in accuracy scores could not be attributed to speed–accuracy tradeoffs. A two-way ANOVA revealed a significant interaction between condition and correct response, $F(1, 23) = 9.4$, $p < .01$, but no main effects (ps $>$.05). Six-year-olds responded more quickly on same trials when faces were misaligned ($M = 1549$ ms, $SE = 157$ ms) than when faces were aligned ($M = 1939$ ms, $SE = 129$ ms), whereas reactions times did not differ across conditions on different trials (Ms = 1779 ms and 1770 ms for misaligned and aligned trials, respectively). This difference in reaction time for misaligned versus aligned same trials (mean = 390 ms and 194 ms for children and adults, respectively) is further evidence of the composite face effect.

DISCUSSION

These results demonstrate a strong composite face effect for unfamiliar faces in 6-year-olds. In the aligned condition, children performed very poorly, presumably because processing the images holistically created the impression that the top halves were always different, despite the fact that on half the trials the two top halves were identical and only the bottom halves differed. Accuracy on same trials increased by 26% and response times decreased by 194 ms. when holistic processing was disrupted by misaligning the top and bottom halves. This finding of a robust composite face effect demonstrates that 6-year-olds process unfamiliar faces holistically. In fact, the size of their composite face effect (26%) was similar to that of adults (23%). This result is consistent with previous studies demonstrating that by age 6, children show an adult-like composite face effect with familiar faces (Carey & Diamond, 1994) and an adult-like whole/part effect for both familiar and unfamiliar faces (Pellicano & Rhodes, 2003; Tanaka et al., 1998).

These data suggest that the improvements after age 6 in the recognition of the facial identity of upright faces are not caused by the onset or increasing strength of holistic face processing. This early development of holistic processing is not sufficient for adult-like expertise, but it may be necessary. For example, when tested with unfamiliar faces Caucasian subjects show a whole/part effect for Caucasian, but not Asian faces, and are much worse at recognizing Asian than Caucasian faces (the classic other-race effect) (Michel, Rossion, et al., in press; see also Tanaka et al., 2004). In contrast, Asian subjects, who had been living a year among Caucasians, showed a strong whole/part effect for both Caucasian and Asian faces, but nevertheless were much poorer at recognizing Caucasian than Asian faces (Michel, Rossion et al., in press).

Holistic processing may facilitate the development of sensitivity to one cue to facial identity—small differences in the metric relationships among facial features, a cue that has been called second-order relations (see Maurer et al., 2002, for a review). Mondloch et al. (2002) created several versions of a single face, "Jane", that differed in the shape of the external contour, the shape of individual features (e.g., the eyes and mouth), or the spacing among features (e.g., the distance between the eyes, the distance between the eyes and mouth). When making same/different judgements about pairs of faces 6-year-olds were adult-like for the contour set and nearly adult-like for the featural set. In contrast even 14-year-olds make more errors than adults for the spacing set (Friere & Lee, 2001; Mondloch, Le Grand, & Maurer, 2002, 2003). Holistic processing may facilitate the processing of second-order relations by making it easier to compare the spacing of features in an individual's face to a normative upright face and to scale the comparison across different distances from which the face is viewed. Thus, holistic processing may be a necessary, but not sufficient, step in the acquisition of expertise in recognizing facial identity—both during development and when learning to recognize other-race faces as an adult. Our results suggest that by

6 years of age (the youngest age tested) adult-like holistic processing is in place for own-race faces.

These results also address the relationship between the effect of early visual experience and rate of normal development. Visual skills mediated primarily by the striate visual cortex show a pattern that fits the Detroit principle: Earlier developing skills (e.g., sensitivity to high rates of flicker) are less affected by visual deprivation and uneven competition between the eyes than later developing skills (e.g., sensitivity to slow rates of flicker). Our earlier results for face processing also fit the Detroit model: Skills that are adult-like by 6 years of age (e.g., recognition of identity based on internal features or external contour) are normal after early visual deprivation, whereas skills that are still improving after 10 years of age (e.g., recognition of identity based on the spacing of features or despite a change in point of view) are impaired (reviewed in Mondloch, Le Grand, & Maurer, 2003). Using the same task as in the current study, we found that children treated for bilateral congenital cataract do not engage in normal holistic processing: Their accuracy was not impaired in the condition where holistic processing makes the task difficult for visually normal subjects, namely aligned same trials. Their accuracy in that condition was significantly *better* than that of the control group and their mean composite face effect was zero (Le Grand et al., 2004). The finding in the current study that an adult-like composite face effect has developed by 6 years of age indicates that the speed of normal development does not predict accurately whether a particular face processing ability will be spared or affected. The noncorrespondence fits with previous findings that visual skills mediated by higher brain areas (e.g., sensitivity to global motion and global form; Ellemberg, Lewis, Maurer, Brar, & Brent, 2002; Lewis et al., 2002) show a more complex relationship to the pattern of normal development than low level visual skills and suggests that the Detroit principle may not apply to higher visual cognition (see Maurer, Lewis, & Mondloch, 2005).

Unlike visually normal adults, 6-year-olds' accuracy on different trials varied across conditions: They were more accurate when the two halves were aligned than when the two halves were misaligned. In fact, 6-year-olds were as accurate as adults in only one condition—on different/aligned trials. Their superior performance on aligned trials when holistic processing did not interfere with making a correct response may be related to their having experienced aligned, but not misaligned faces, in the real world. Unlike adults, they may not be able to rapidly adopt an effective strategy for the unusual stimulus class of misaligned faces. A similar pattern of better performance on aligned than misaligned different trials has been found when adults were asked to recognize the expression in the top half of composite faces (Calder & Jansen, 2005, Exp. 3). The pattern of results for 6-year-olds on different trials makes their impaired performance on same aligned trials all the more impressive: Despite an overall difficulty in processing the misaligned faces, they were more accurate in seeing the top halves were the same when the faces were misaligned rather than aligned to create holistic interference from the different bottom halves. Future studies are necessary to clarify the processing skills that underlie the improvement in face processing after 6 years of age, and whether they build on the holistic processing that is present by at least age 6 for both familiar (Carey & Diamond, 1994) and unfamiliar faces (this study).

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