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Citation for final published version:

Shah, Nilpa, Dakin, Steven C., Redmond, Tony and Anderson, Roger S. 2011. Vanishing Optotype acuity: repeatability and effect of the number of alternatives. *Ophthalmic and Physiological Optics* 31 (1), pp. 17-22. 10.1111/j.1475-1313.2010.00806.x

Publishers page: <http://dx.doi.org/10.1111/j.1475-1313.2010.00806.x>

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1 **Vanishing Optotype Letter Acuity: Repeatability and Effect of the**
2 **Number of Alternatives**

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9

10

11 **Abstract**

12 Vanishing Optotype letters have a pseudo high-pass design so that the mean
13 luminance of the target is the same as the background and the letters thus
14 'vanish' soon after the resolution threshold is reached. We wished to
15 determine the variability of acuity measurements using these letters compared
16 to conventional letters, and in particular how acuity is affected by the number
17 of alternatives available to the subject.

18 Acuity was measured using high contrast letters of both conventional and
19 Vanishing Optotype design for three experienced normal subjects. Thresholds
20 were determined for central vision in a forced choice paradigm for two
21 alternatives (2AFC; AU and OQ), 4AFC (AQUO), 6AFC (QUANGO) and
22 26AFC (whole alphabet) using a QUEST procedure. Three measurements
23 were made for each condition.

24 Threshold letter size was always larger for the Vanishing Optotypes than
25 conventional letters, although the size of this difference (0.11 – 0.34 logMAR)
26 depended on the number of alternatives and what they were. The effect of the
27 number of AFC, and the individual letters employed, was smaller for the
28 Vanishing Optotypes, implying that they are more equally legible than
29 conventional optotypes. Variability was also lower for the Vanishing Optotype
30 sets (0.01 – 0.03 logMAR) than the conventional letter sets (0.03 – 0.06).

31 The smaller effect of the number of alternatives, combined with more equal
32 discriminability and lower threshold variability, implies that Vanishing
33 Optotypes may be appropriate targets from which to design letter charts to
34 measure small clinical changes in acuity.

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Introduction

Visual acuity measurements remain of the utmost importance in forming clinical decisions when monitoring disease progression and the efficacy of therapy. Any test measuring visual acuity should provide precise and repeatable measurements in order to reliably determine whether or not a significant change in performance has resulted from either abnormality or treatment. Variability can originate from a variety of sources including the observer, the clinician, the overall design of the test chart or the psychophysical testing procedure, and recommendations have been made to minimize at least some of these.^{1, 2}

LogMAR acuity charts were designed to remove many of the recognized limitations of conventional Snellen charts^{3, 4} and are becoming more widely used in both clinical and research settings. While the letter-by-letter scoring system in theory allows step sizes of 0.02 log units, test-retest variability remains a problem for these charts with reported 95% confidence intervals between 0.06 and 0.19 log units for normal, focused eyes,⁵⁻¹³ increasing significantly with the presence of either optical defocus¹⁴ or retinal disease.¹⁵ ¹⁶ found significant differences in logMAR scores as a result of different termination rules and numbers of alternatives during a forced choice test (AFC). He suggested that between-subject variability arises as a result of different patient criteria where a subject may not be forced to identify small letters, depending on testing rigour. For Bailey-Lovie or ETDRS charts, employing letter-by-letter scoring, Carkeet suggested termination of the test when four or more mistakes are made on a line.

Although the Sloan¹⁷ letter set, employed by modern ETDRS charts, was originally devised to have closely similar discriminability, closer examination of the literature indicates that this may not be the case.¹⁸ If a test-chart's within-line discriminability difference is greater than the between-line discriminability difference, the test will be very variable. But is discriminability the inherent property of an individual letter or does a letter's discriminability depend on what, and how many, other letters it is being discriminated from? Visual acuity results will be affected by the probability that the subject will be able to

1 discriminate the optotype from any number of other alternatives available.
2 Carkeet¹⁶ found that the mean and standard deviation of logMAR scores was
3 significantly affected by the number of forced choice alternatives. The
4 increase in the mean is not surprising since, as the number of alternatives
5 increases, the degree of letter uncertainty increases in that there are more
6 likely to be other letters that look similar to the presented one, meaning that
7 the letter must appear visibly different from all of the other possibilities before
8 the subject ventures an identification. However, this greater letter uncertainty
9 does not necessarily lead to greater threshold variability; in fact the opposite
10 is likely true since the subject is less likely to guess correctly even when the
11 letter is unresolvable.

12 Several studies have shown that the visual system relies on the lower object
13 spatial frequency content for conventional letter recognition, in both foveal and
14 peripheral vision.¹⁹⁻²⁵ Several of these studies also indicated large differences
15 in the spatial frequency content at these low object frequencies^{20, 24, 26}
16 resulting in some letters remaining easily recognizable when small and
17 blurred, while others do not. However, if these lower frequencies, where
18 conventional letters differ substantially, are removed, the visual system must
19 rely on the higher spatial frequency content and the letters may thus become
20 more equally discriminable. If this is so, the effect of different numbers of
21 alternatives may also become less.

22 'Vanishing Optotype' targets, first described by Howland *et al.*,²⁷ have a
23 pseudo 'high-pass' design in that they are typically constructed of a dark core
24 surrounded by light edges (or vice versa), the mean luminance of which is the
25 same as the background (Figure 1). While such stimuli are not truly high-pass,
26 their construction means that the detection and resolution thresholds are
27 closely similar in the fovea²⁸ and, unlike conventional letters, the characters
28 'vanish' almost as soon as the resolution threshold is reached.

29 The Vanishing Optotype target design has been employed in High-Pass
30 Resolution Perimetry (HRP)²⁹ and is currently employed in tests such as the
31 paediatric Cardiff Acuity Test which uses preferential looking techniques to
32 determine visual acuity in children and in those unable to participate in
33 conventional optotype identification tests.^{30, 31} However, despite some
34 academic interest, Vanishing Optotypes have, to date, received relatively little

1 attention in clinical visual acuity testing. This study aims to determine the
2 variability of acuity measurements using Vanishing Optotype letters relative to
3 conventional letters to test the hypothesis that, if lower frequencies are
4 removed, the letters become more equally discriminable. This being the case,
5 the number of alternatives available to the subject should have less effect on
6 acuity measurements with Vanishing Optotypes. The results of this would be
7 valuable when thinking about new test chart designs.

9 **Methods**

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11 Ethical approval for this study was obtained from the relevant UCL research
12 ethics committee and all procedures adhered to the tenets of the Declaration
13 of Helsinki. All tests were conducted on three experienced psychophysical
14 observers (NS, RSA and TR), with no ocular abnormalities and corrected
15 visual acuities of 6/5 or better. The refractive error was carefully corrected
16 prior to the start of each testing session using trial lenses. Subjects NS and
17 RSA were emmetropic while subject TR had a mean spherical refractive error
18 of -3.00D.

19 Foveal visual acuity measurements were made monocularly in the right eye of
20 all subjects using both conventional and Vanishing Optotype letters. The
21 Vanishing Optotypes were constructed with an inner black 'core' flanked by a
22 white border of half the width of the central section. This created a target with
23 the same mean luminance as the background and thus had a pseudo high-
24 pass design. For both stimulus types, the letter height and width were five
25 times the 'stroke width', which in the case of the Vanishing Optotype
26 consisted of the dark middle bar with its two white flanks. All optotype stimuli
27 were generated using MATLAB v7.6 (Mathworks, Inc., Natick, MA, USA) and
28 were presented at high contrast (94.6%) on a γ -corrected high-resolution
29 (1280 x 1024 pixels) Dell Ultrascan P991 CRT monitor (Dell Corp. Ltd,
30 Brackness, Berkshire, UK) driven by a Macintosh computer (Apple Computer
31 Inc, Cupertino, CA, USA). Presentation time was 500ms and the CRT monitor
32 had a background luminance of 53.9cd/m². All testing was conducted at 3.8m
33 under low room illumination to avoid screen reflections; at this distance the

1 screen subtended 4 x 5.3 degrees and one pixel subtended 0.25 minutes of
2 arc. Scaling of stimuli was achieved using the OpenGL capabilities of the
3 computer's built-in graphics card (ATI Radeon X1600; AMD, Sunnyvale, CA,
4 USA). This (bilinear interpolation) procedure allowed us to display stimuli of
5 arbitrary size with sub-pixel resolution while retaining accurate representation
6 of their (balanced) luminance structure.

7 For each subject, threshold visual acuity was determined for both
8 conventional and Vanishing Optotypes for differing numbers of AFC using
9 QUEST, an adaptive psychometric procedure.³² In this paradigm, the size of
10 any displayed letter is determined by knowledge of the previous responses,
11 with trials evenly spread on a decimal/log axis. The prior density function was
12 limited by the maximum and minimum displayable letter size on the screen
13 and an initial letter size of 115.8 x 115.8 minutes of arc was displayed. The
14 slope (β) of the psychometric function used was set to 3.5 which is widely
15 used in psychophysical literature. The final acuity threshold was determined
16 by QUEST's built in maximum likelihood estimation procedure of threshold.
17 Each test run involved 50 letter presentations. The alternative choices in each
18 session were 2AFC (AU and QO), 4AFC (AQUO), 6AFC (QUANGO) or
19 26AFC (whole alphabet) (Figure 1).

20 The viewing distance was 3.8m and the subject's verbal letter identification
21 was entered on the keyboard by the examiner. Responses were limited to the
22 letter set available for each test. These were displayed in the corner of the
23 screen to remind subjects of the choice of letters. The final threshold size
24 under each AFC condition was recorded and converted to logMAR where, for
25 the Vanishing Optotypes, the 'stroke width' includes both the central dark bar
26 and its white flanks. Three repeat measurements were made for each
27 condition for all subjects.

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30 **Results**

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32 The mean of the three repeat thresholds measurements obtained for each
33 subject was plotted in logMAR values for each AFC condition for conventional
34 letters and for Vanishing Optotypes (Figure 2). Error bars represent the

1 standard deviation of the three repeat measures. For all AFC conditions,
2 threshold letter size was significantly larger for the Vanishing Optotypes than
3 for the conventional letters at the 0.05 significance level, except for QO
4 ($p=0.08$). However, the actual difference in performance between the two
5 stimulus types (0.11 – 0.34 logMAR) was not only dependent on the number
6 of alternatives but also on what they were. Interestingly, both the smallest and
7 largest between-optotype difference occurred under 2AFC conditions for the
8 letters OQ and AU respectively. The mean threshold acuity for conventional
9 optotypes ranged from -0.33 (AU) to 0.06 (QO), a 0.39 log difference.
10 Significant differences in discrimination thresholds ($p<0.05$, paired t-test) were
11 found between AU and all other AFC combinations. Significant differences
12 were also found between QO and AQUO, QO and QUANGO, and AQUO and
13 QUANGO (all $p<0.05$).

14 The Vanishing Optotype discrimination thresholds were less affected by the
15 number of AFC, and the individual letters employed, compared to the
16 conventional letters. The discrimination thresholds ranged only from 0.01
17 (AU) to 0.17 (QO), a 0.16 log difference. Significant differences ($p<0.05$,
18 paired t-test) were again found between AU and all other AFC combinations,
19 but not between any other AFC combinations. The effect of the differing
20 numbers of AFC is thus less overall for the Vanishing Optotypes.

21 Figure 3 shows a plot of the mean standard deviation as a percentage of the
22 logMAR thresholds for each of the letter types. It can be seen that the
23 variability was lower for the Vanishing Optotypes (0.01 – 0.03 log units),
24 compared to the conventional letters (0.03 – 0.06 log units).

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26 **Discussion**

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28 As previously stated, visual acuity measurements contribute significantly to
29 clinical decision making with regard to disease progression and treatment
30 efficacy. A measured deterioration in visual acuity often forms one of the
31 criteria for further intervention, but only if it is deemed clinically significant. For
32 this reason, any test of visual acuity should be both precise and repeatable.

33 The aims of this study were to determine the repeatability of acuity
34 measurements using Vanishing Optotype letters and to investigate how acuity

1 using these is affected by the number of alternatives available to the subject.
2 The results suggest that, overall, visual acuity measured using Vanishing
3 Optotypes is 'poorer' than conventional letter acuity, regardless of the number
4 of AFC. This conclusion is the logical result of directly comparing the
5 threshold letter heights of the two letter types. However, as previously
6 mentioned, the letter types are composed of different spatial frequencies in
7 the Fourier domain and several studies have shown that the visual system
8 relies on the lower spatial frequency content for conventional letter recognition
9 in both foveal and peripheral vision.¹⁹⁻²⁵ If lower spatial frequency information
10 is removed, as in the Vanishing Optotypes, the visual system must rely on the
11 high frequencies for identification,³³ hence the 'poorer' performance observed
12 for these characters. However, the aim of this study was not so much to
13 compare absolute differences in threshold letter size between the two target
14 types, but to determine the effects of different numbers of AFC and threshold
15 variability. From a clinical perspective, this is more important.

16 Vanishing Optotypes are less affected overall by the number of alternatives
17 available and what they are, likely because, as hypothesized, they are more
18 equally discriminable than conventional optotypes. As mentioned, several
19 studies have indicated that the visual system utilizes the low spatial
20 frequencies for conventional high contrast letter acuity. Some of these studies
21 also indicated large differences in the spatial frequency content at these low
22 object frequencies.^{20, 24, 26} If two letters are very different in their low spatial
23 frequency content, they should remain discriminable down to very small sizes.
24 Two letters that are more similar in their low spatial frequency content force
25 the visual system to rely on higher spatial frequencies for discrimination, thus
26 their acuity threshold will be larger. This would explain why AU is much more
27 discriminable than OQ in conventional form (Figure 2). Under 4AFC
28 conditions (AQUO) performance fell in between the two 2AFC conditions. As
29 the AFC number rises to 6 and 26 the letters become more 'similar' (on
30 average), increasing letter uncertainty and leading to larger discrimination
31 thresholds, i.e. each letter must begin to look more 'like itself' rather than 'not
32 the others' in order for the subject to confidently identify it.

33 However, if these lower frequencies, which give rise to large inter-letter
34 discriminability differences for conventional letters, are removed, the between-

1 letter differences should become smaller and much more uniform. This is
2 borne out in Figure 2 where, except for AU, there is no significant difference in
3 performance with different AFC conditions. Using the higher frequencies there
4 seems to be closer similarity and greater letter uncertainty, even under low
5 AFC conditions. It may even be that, on filtering out the low frequencies, the
6 visual system switches to a strategy based less on spatial frequency content
7 and more on localized features.

8 In addition, measurement variability was found to be lower using Vanishing
9 Optotypes (Figure 3). This has been attributed to the fact that conventional
10 letters have two distinctly different thresholds for detection and resolution.³⁴
11 point out that variability can arise as a result of the transitional zone between
12 these two points, as it is known that subjects can learn to recognize blurred
13 images that are close to the detection threshold. Any ability to recognize
14 blurred images relies on the presence of different low spatial frequencies in
15 the targets that permit discrimination (e.g. 'A' from 'U') even though they no
16 longer resemble the actual letters. With conventional letters, under greater
17 AFC conditions, different low spatial frequency content will lead to large inter-
18 letter legibility differences. If this difference *within* steps is significantly greater
19 than *between* steps, increased variability in any staircase threshold measure
20 will result.

21 In conclusion, the smaller effect of the number of alternatives, combined with
22 more equal discriminability and better repeatability, at least in normal
23 subjects, suggests that Vanishing Optotypes may be promising targets from
24 which to design clinical letter charts. More work remains to be done to
25 understand the differences in how the visual system resolves the Vanishing
26 Optotypes compared to conventional letters. In addition, we have yet to
27 examine the effects of optical defocus and ocular abnormality on Vanishing
28 Optotype acuity to determine whether these stimuli are appropriate to
29 measure clinically significant changes in vision.

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1 **Acknowledgements**

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3 This work is supported by an award from the NIHR Biomedical Research
4 Centre for Ophthalmology, Moorfields Eye Hospital NHS Foundation Trust &
5 UCL Institute of Ophthalmology.

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- 20

1 **Figure legends.**

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3 Figure 1. a) the 2, 4 and 6 Alternative Forced Choice Vanishing Optotype
4 letter set and b) the 26 Alternative Forced Choice Vanishing Optotype letter
5 set.

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7 Figure 2. LogMAR values for all three subjects under each AFC condition for
8 a) conventional letters and b) Vanishing Optotypes. Error bars represent
9 standard deviation of three repeat threshold measurements.

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11 Figure 3. Mean standard deviation of the logMAR thresholds for conventional
12 letters (filled symbols) and Vanishing Optotypes (open symbols).

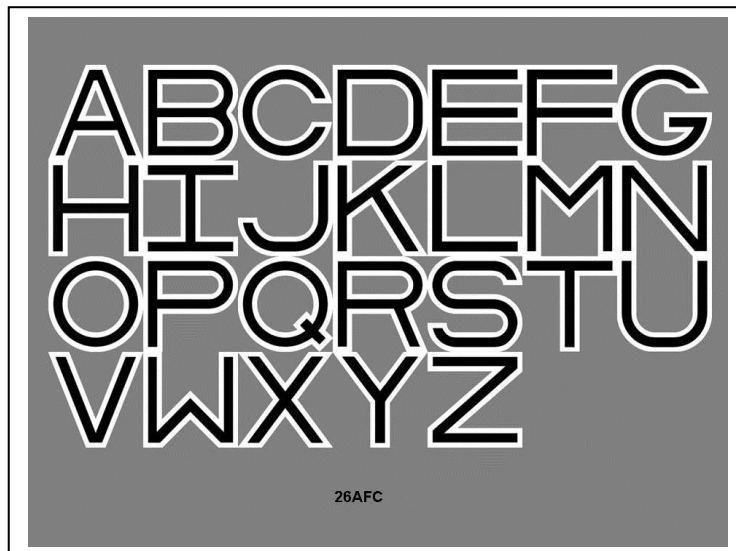
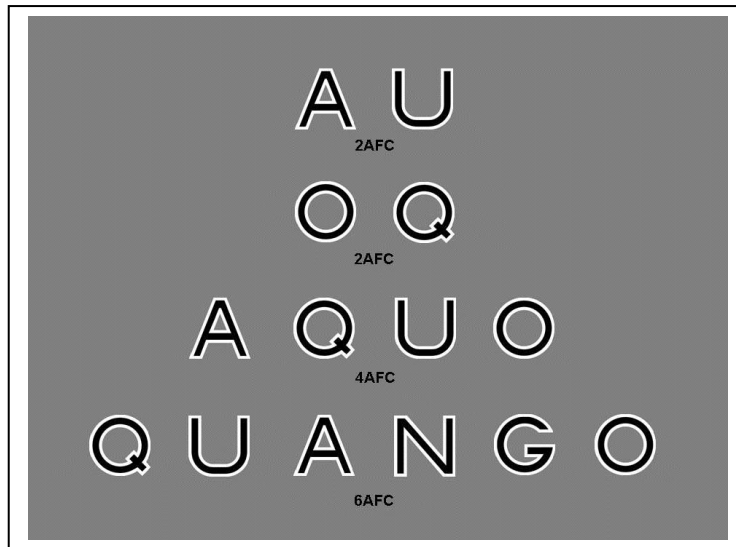
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1 Figure 1.

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1 Figure 2.

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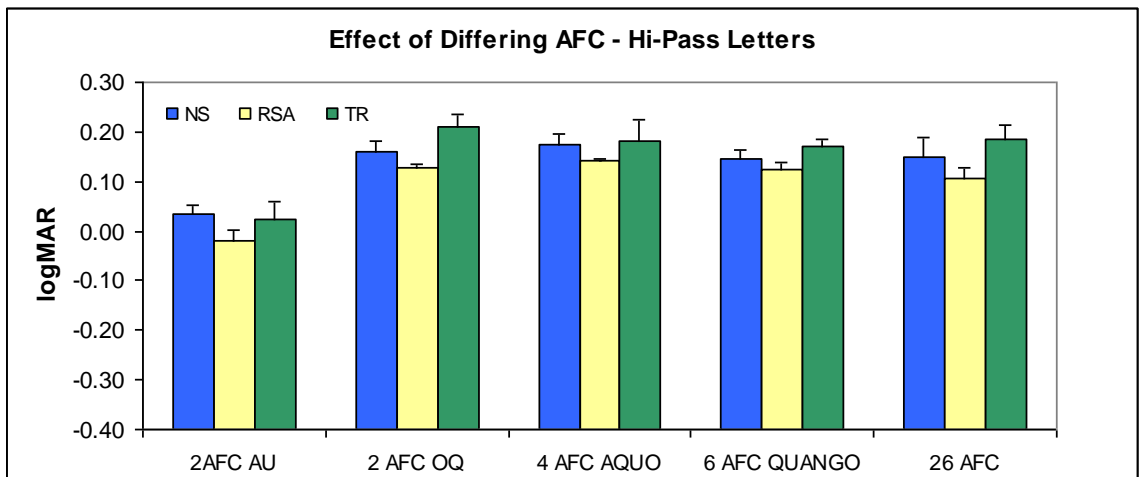
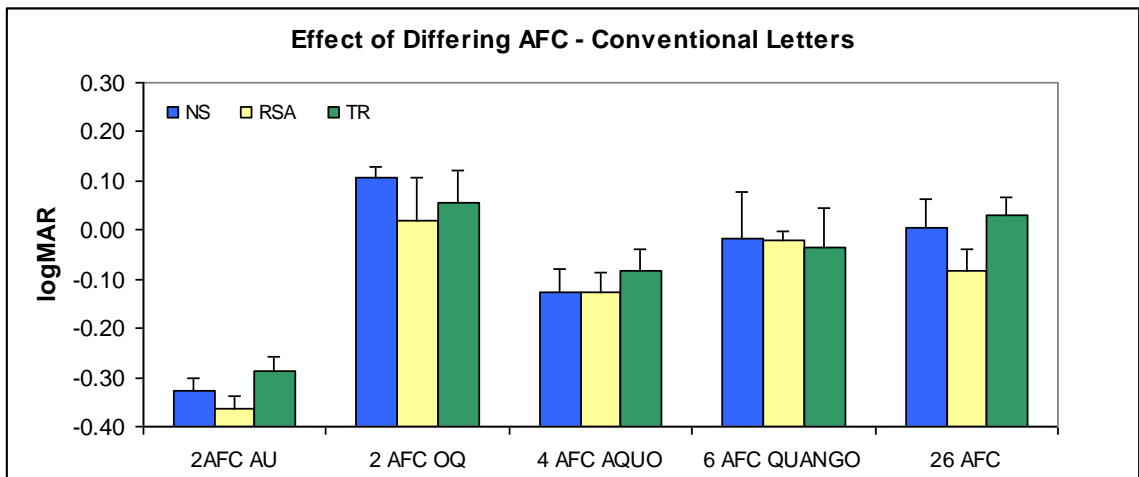
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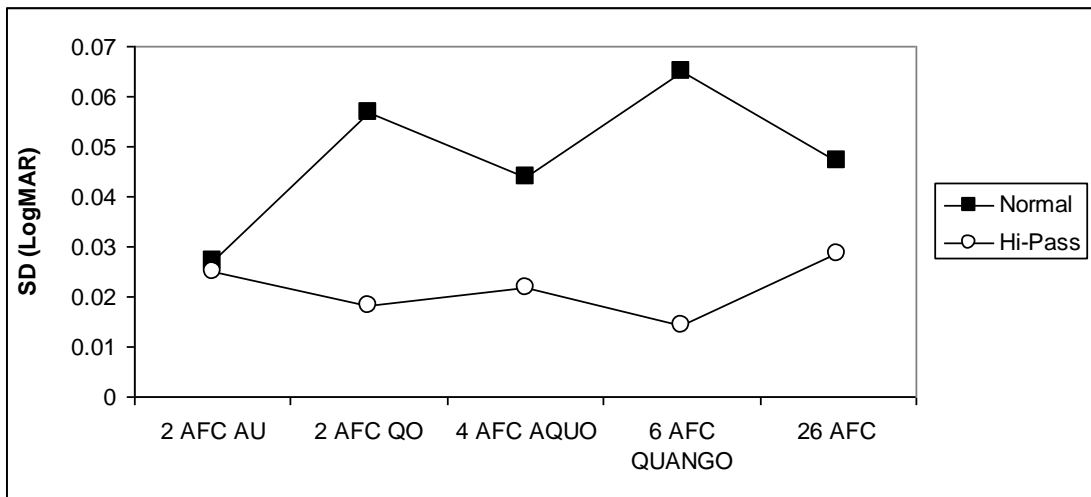
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1 Figure 3.



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